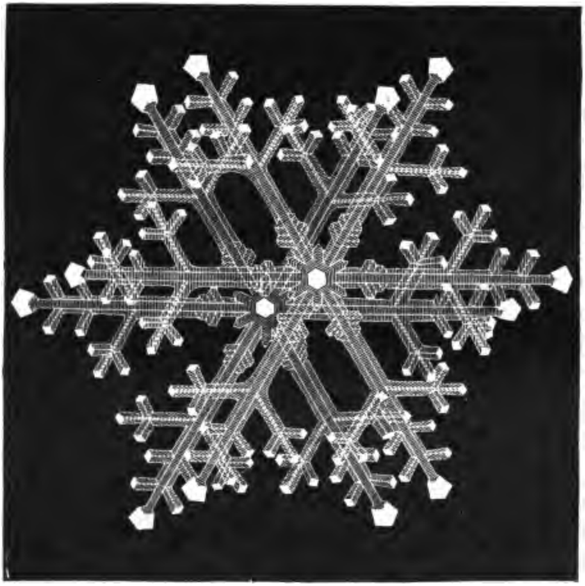
AUNT RACHEL'S LETTERS ABOUT AIR AND WATER

1. Taine's Literature English
2. Science — [illegible], 1871
2 — T. D.

WATER AND AIR.

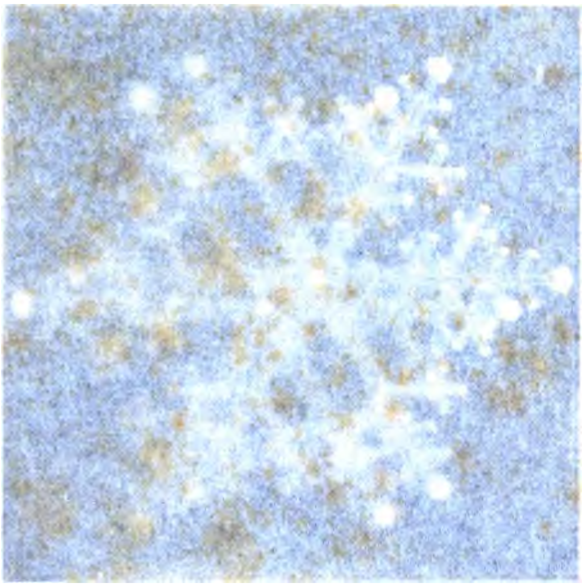
LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

SNOW-FLAKE MAGNIFIED.



(*Taken from* 'Glaciers of the Alps,' *by kind permission of* Prof. Tyndall.)

Frontispiece.



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AUNT RACHEL'S LETTERS

ABOUT

WATER AND AIR.

A FEW FACTS ABOUT
HEAT IN RELATION TO THESE SUBSTANCES, TOLD
IN SIMPLE LANGUAGE.

LONDON:
LONGMANS, GREEN, AND CO.
1871.
LH

PREFACE.

THIS little book makes no pretence whatever to teach science systematically. The writer's hope is that by performing the experiments described in it, children (especially the older classes of elementary schools) may be led to take an interest in a few natural facts, and thus be prepared to profit by more regular teaching.

February 1871.

LIST OF ILLUSTRATIONS.

AUNT RACHEL'S LETTERS.

I.

(First we must say a little about Aunt Rachel herself. She is an 'Old Maid,' or at least she seems so to Ned and Annie, her nephew and niece, though she is not really old. She lives with her father and mother, and helps them to take care of their farm. She was to have been a governess, and for some years lived in London with a cousin who kept school, working hard at her own education. But when her sister married she came home to supply her place. Very well she did it, but without losing the tastes formed during her school life. Her chief amusement was reading such easy scientific books as she could get, and trying as many experiments as she could find time for. The queer 'messes' which she kept in her room often puzzled and

amused her friends. When Ned and Annie came in the summer to the farm, she liked to show them the country sights she loved so much, and watch with them the birds and flowers and insects. When the children left, lamenting that their father's shop was in a dingy street, she promised to write and tell them of beautiful things which might be seen and watched even in a smoky town. This is her first letter.)—

My dear Children,

I have not forgotten my promise of helping you to find things to think about and admire, even in Little George Street. First let us talk about Water. I don't mean to give you an object lesson, like what you used to have at school when you were very little, telling you that water is liquid, transparent, colourless, and so on. You can see all that without my help. I want to point out some things which you are not likely to observe unless you look for them carefully. Sometimes I shall describe experiments, and I strongly advise you to make them for yourselves, if you can; indeed, unless you do, you will probably find my letters very dull.

You know that ice is solid water, and that it is cold which makes it grow solid. You know too that ice floats in water. Now let us think *why* it floats. 'Because it is lighter.' Yes, certainly. But a pound of water will make a pound of ice,—it does not *lose* its weight by freezing. It expands (that is, takes up more room) when it turns into ice, and so, if you take equal bulks of ice and water, the ice is the lightest. Take two pint mugs, one filled with water, the other with a lump of ice exactly fitting it; that containing the water will be heaviest. If you melt the ice you will see why, for the melted ice will not quite fill the mug.

Anything will float in water which displaces, pushes out of its way, an equal weight of the water. I will try to put that in clearer words. You sailed your little boat on the pond here. It weighed perhaps six ounces. When you put it into the water, it sank till it had displaced six ounces of water, and then it sank no lower. When you put an ounce of shot into it, it sank till it had displaced another ounce of water. When one day you put a heavy stone into it, you made the little boat so heavy that it was not large enough to displace an equal weight of water, and you

remember that it sank to the bottom, wetting its white sails and gay flag. Sea-water is heavier than fresh, and so your ship would have drawn less water in the sea than in the pond; it would not have had to sink so deep to push out of its way the necessary quantity of water. For this reason it is easier to swim in the sea than in a pond, when they are equally smooth. Perhaps you don't see what all this has to do with the ice. Instead of your boat, put into the water a lump of ice weighing six ounces. It will sink till it has displaced six ounces of water; but as six ounces of ice take up more room than six ounces of water, it follows that some of the lump will be above water.

Water expands with enormous force in freezing. I have seen some thick iron bottles burst by it. First the bottles were filled with water, and the iron stoppers screwed tightly down. Then they were put to freeze, in a freezing mixture, about which I may perhaps tell you more another time. Presently there was a cracking noise, and one of the bottles had a piece actually burst out, while the other had a great crack. So determined was ice to make way for itself, that not even the

thick iron could keep it in. You can try such an experiment yourselves, with an old glass bottle, if you like. You must fill it quite full, cork it, tie down the cork, and put it out of doors in the next hard frost. The ice will probably either burst the bottle or force out the cork. Was not the kitchen flooded in the thaw after the long frost last winter? The pipes had been burst by the water freezing in them, and, when the thaw came, it melted and ran out of the holes thus made. That was an unpleasant instance of the expanding power of water when it freezes.

Water is almost the only known substance which takes up more room when it is solid than when it is liquid. Lead takes up less room in a lump than when it is melted. Take a piece of wax and melt it in a spoon over the candle. When it cools you will find that it shrinks so much that the edges separate from the spoon. The tallow or composition of which candles are made is poured hot into the moulds, and when cold and solid it is so shrunk that it is quite loose from the sides of the mould.

Now let us think what would be the consequence if water, instead of expanding when it

solidifies, *contracted*, that is, shrank, like other substances. The ice, you know, would sink to the bottom of the ponds. More ice would form very quickly if the top were thus left bare and exposed to the cold air. This new ice would sink too, and so on till the whole pond was turned into a solid block, and all the fish in it were killed. But as it is, the ice floating on the top covers the water underneath and keeps it much warmer than it would be without such a covering, while the fish swim about safely. If ice had not been lighter than water, I suppose we should have had no fish in this climate. The first hard winter would kill them. Now I do not say that ice has been made lighter than water in order that fish may live through hard winters. But this is an instance of what we may often notice; one thing fits into another, so that if one little circumstance were changed, the consequences would be greater than we should expect. It seems a very little thing, this difference between water and almost every other substance. You would not think it would be at all an important thing that it should expand as it turns solid. Yet it matters a great deal to the fish, as you will remember the next

time you see them swimming about under the ice, with its hard clear covering above them like a roof to keep them warm. The more we learn about what God has made, the more we shall admire the way in which one part fits into another, and the more we shall see that things which we call trifles are quite necessary to the well-being of something which we call very important. But God cares for little things as well as great, and forgets nothing that He has made. This is a comfortable thought with which to end my letter, is it not? For if God cares so well for what seem to us like little things, how much more will He fit our place for us, and us for our place! Only let us take care to be always, like good soldiers, at the post where He has set us, instead of looking about for something which pleases us better. There is a saying, 'For every stone there's a hole in the wall,' and we may be sure that the Great Builder of creation will put each stone into the place which fits it best.

Believe me, dear Children,

Your affectionate Aunt,

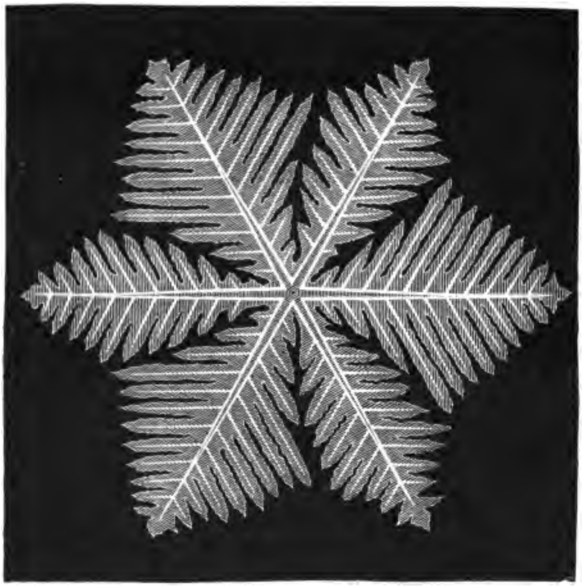
RACHEL.

II.

My dear little Niece and Nephew,

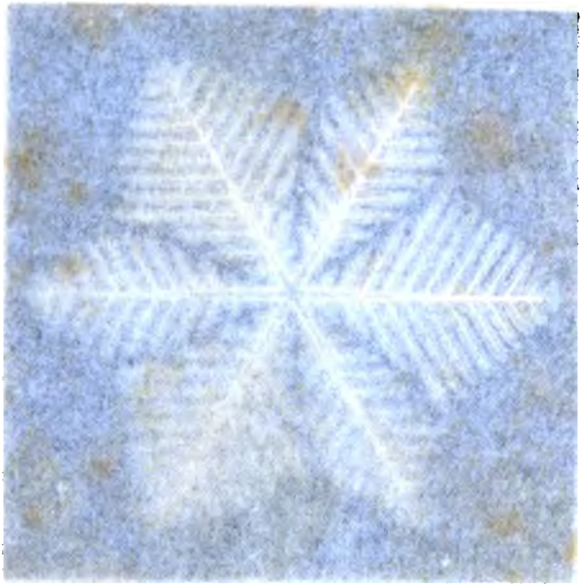
I am glad to hear from your mother that you were successful in your experiments, showing that water takes up more room when it is solid than when it is liquid, and tallow less. I should have been glad to hear that you had tried the experiments, even if you had failed, for I am sure that it is only trying to do these things yourselves which will give you any interest in what I tell you. If ever you fail, you must write and tell me, and we will try to find out where we have made a mistake, for you know, if we go the right way to work, we are sure to succeed, since there is no *chance* in these things. To us God has given the power of choosing whether we will obey His will or not; but to the materials which make up earth and air and water He has given no such choice. He guides all according to certain and unerring laws, from the sun and moon down to the smallest grain of sand,—ay, and further still—down to atoms too small for us to see. By carefully and patiently watching what goes on around us, we may learn something about those laws, but the more we learn, the more we

SNOW-FLAKE MAGNIFIED.



(*Taken from* 'Glaciers of the Alps,' *by kind permission of* Prof. Tyndall.)

To face p. 9.



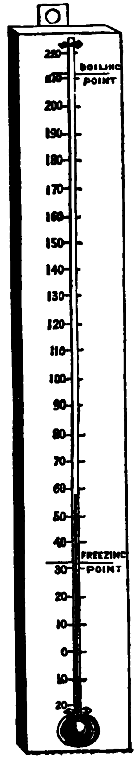
shall be convinced that what we have learnt is little indeed compared with what we know nothing about. Thus it is that the most truly wise and learned men are amongst the most humble and reverent.

The first experiment I shall describe to-day is very simple. Take two pieces of ice with moist sides and press them gently together. They will freeze together and form one lump. The film of moisture between the two lumps is frozen by having the cold ice on both sides of it. Even in warm water two pieces of ice will do this; but if they are so cold that their sides are dry and frozen hard, they will not freeze together, because there is no moisture to serve as cement. I suppose this is the reason why snow will not 'bind' when it is frozen so hard as to be dry and crunching under one's feet. You know how difficult it is to make a good snow-ball then. Now, snow is water which has been frozen high up in the air, in such a way that, instead of forming shapeless blocks, each little morsel is like a beautiful star or flower. Look closely at a flake of snow, and you will see one or more of these crystals,—many often stick together,—each with six points or rays. These rays are often branched and di

like fern-leaves, and take a number of fanciful shapes, but the star is always six-sided. You will see them more plainly with a magnifying-glass. If you have not got one, ask your old friend Mrs. Smith to lend you her spectacles. Perhaps you think I am joking, but I am not. Of course, if you put them on your nose, as she wears them, you would see a great deal worse instead of better; but if you hold the spectacles near to the flake of snow, and your eye a foot or a foot and a half from them, they will make the flake look larger.

Water when pressed with a heavy weight requires more cold to make it freeze than when it is not pressed. The cold, you know, makes it expand, and as the weight tends to prevent it from expanding, it also tends to prevent it from freezing. So too, ice, when pressed very hard, will melt before reaching that degree of heat which would melt it under other circumstances. (This degree of heat we call the *melting point* of ice, or *freezing point* of water; that is, the point at which a little more heat would make ice melt, or a little more cold would make water freeze.) When the pressure is taken off, the ice grows

solid again. You have seen a thermometer; you know that it is a glass tube filled with mercury or spirit, which stands higher in the tube when it is hot than when it is cold. The tube is marked with figures, for convenience in observing the height of the mercury. In English thermometers the freezing point of water is usually marked 32°. Greater heat than this makes the mercury rise above 32°. Greater cold makes it sink to some lower number. We say that the freezing point of water is *lowered* by pressure; in other words, ice, when under pressure will melt when the thermometer is below 32°,—let us say at 28°,—and water under pressure will remain liquid till the thermometer has sunk below 32°.



I have seen powdered ice put into a mould and pressed with great force in a machine. First the air was pressed out from between the morsels of ice; then each morsel became

partly liquid as the crushing went on, and the freezing point was lowered, and there was found in the mould, when it was taken out of the machine, a solid block of ice, shaped like the mould. The morsels of ice had been squeezed close together in their half liquid state, and when the pressure was taken off they froze again into one piece. I am sorry you cannot do this for yourselves; I have told you about it to make clear what I am now going to tell you.

On high mountains a great deal more snow falls than melts, but the mountains do not get higher with the piled-up snow. What becomes of it? A little snow at the top melts in the sun, and trickles down to the bottom of the mass. Also the weight of the upper portions of snow acts on the under portions like the squeezing machine in the last experiment, pressing them till they are partly melted. Thus the edges of the flakes become moistened, the weight of the snow above presses out the air from between them, they freeze together, and the delicate snow-flakes are squeezed into solid blocks of ice. More snow falls, and makes more ice above, which presses the first ice 'y out of its way down the mountain. Thus ›rmed the *glaciers* of which you have heard.

They stretch down into the warm valleys, and melting, often form great rivers. The Rhone and Rhine both rise in glaciers. Fresh ice at the top supplies the place of that which melts, and is in its turn pressed down the valley by the ice above it. It moves so slowly that you could not see it move at all, if you looked at it; but if a stake is stuck into the ice, and a mark made on the bank close by it, the stake will be found to have moved a foot or two past the mark by the end of a day. This is the fastest that it ever moves. Often it is only a few inches a day. It is a case of 'slow and sure,' for it moves with immense force. It scrapes stones and earth, and great pieces of rock from the side of its bed. You must not fancy a glacier to be a smooth river of ice, better for sliding on than other rivers because it is frozen all through, and there is no danger of tumbling into water. On the contrary, as it moves along its rugged and uneven bed, it is broken and split and piled up in all manner of shapes. It is a very difficult thing to cross a glacier, and many a man has lost his life by falling into one of the huge cracks or rather chasms called *crevasses.*

I will stop now, for I want to tell you rather

about things close to you than about what you are never likely to see. Good-bye—I hope the frost will last till we have done talking about ice.

I am, your affectionate Aunt,

RACHEL.

(Soon after sending her second letter, Aunt Rachel received one from Ned,—the longest which he had ever written. This is the letter, as he wrote it, except the spelling, which was after a fashion of his own.)

Dear Aunt RACHEL,

Only think how jolly! We made two bits of ice freeze together in a cup of hot water to-day at breakfast, and father had actually *never* seen it before, and he was quite surprised. And then he said he'd puzzle us. So he got a lot of snow in a tin can, and put a lot of salt to it, and wetted the bottom of the can, and put it on a stool before the fire. And the can froze to the stool, and the snow in it melted, and Annie put her hand into it, and it was so cold that it made it ache till she nearly cried. And father said we must ask you about it.

From your affectionate Nephew,

NED.

III.

My dear Ned,

I will try and explain to you your father's experiment. But I am afraid a thermometer is necessary to make it quite clear. Common ones, such as would answer our purpose quite well, are sold very cheap. You are pretty sure to be able to get one for a shilling, and I have seen them cheaper. So I advise you to save up the chance pennies that are apt to be spent on very short-lived treats, and buy one. Then go out early one of these cold mornings, and get some very cold ice or frozen snow. Snow is the best, because you can plunge the thermometer easily into it; but if you pound the ice, or break it up into little pieces, it will do. Put it into an old saucepan, and plunge the ball of your thermometer into it. If it is freezing hard, and if you are quick, so as not to let the snow get warm with the heat of the room, it may very likely make the thermometer sink some degrees below 32°, which, as you know, is the freezing point of water. Now warm it. Perhaps the most convenient way to do this will be by hold-

ing the saucepan over the flame of a candle. The thermometer will rise to 32°. Then the snow will begin to melt, but the thermometer will stop rising. Why? Do you think the candle has warmed the saucepan as much as it can warm it? No; because the snow goes on melting, and if we go on watching, we shall see that as soon as all the snow is melted, the thermometer begins to rise again. It would rise steadily till the water boiled, if we waited for it to do so, but I think your patience would be pretty sure to be tired out first. Besides, common cheap thermometers are not made to go as high as the boiling point of water, which is marked 212° on English thermometers. You must watch yours carefully, and take it into a cool place as soon as the liquid has risen nearly to the top of the tube. If you were to heat it much more the tube might burst, and the thermometer would be spoiled. But what became of the heat which the candle gave out all the time that the snow was melting, while the thermometer stood still? In melting the ice it was made *latent*, that is, it was so changed that we annot discover it in the water. It is not lost, wever, for when the water freezes it will give

it out again; and it makes the freezing go on much more slowly than it otherwise would do, as some of it goes to warm that part of the water which is still liquid. All liquids have more or less of this 'latent heat' hidden away in them. When they become solid they give it up. When they melt again they *absorb* it (that is, drink it in) from whatever is warmer than they are. Thus whatever is close to the solid is cooled, and the melting goes on slowly. Or if the surrounding air is cooler to begin with than the solid which is melting, the solid itself is chilled by its own heat being made latent, till it is cooler than the air. After heavy snow, a sudden thaw often causes bad floods. It would happen so much oftener if it were not for this check on the rate at which the melting goes on. In water, the quantity of latent heat is very great. One pound of ice in melting will absorb as much heat as would make 143 pounds of water one degree hotter by the thermometer.

There are other ways of melting solids besides heating them. You know salt and sugar melt when they are put into water. But they absorb

heat in melting. In dissolving the salt the water is chilled. I do not know whether your thermometer will be delicate enough to show this. I have seen one, which was not a particularly good one, sink two degrees when a spoonful of salt was put into the water in which it was standing; and this though the salt was if anything warmer than the water, rather than colder.

Now mix together snow, or pounded ice and salt. The salt melts, just as when it is put into water, and what will perhaps surprise you more is, that the ice melts too, I am afraid I cannot tell you why. Both melt, and both absorb heat and are very much chilled. Thus when your father froze the tin mug to the stool, the snow and salt in the mug robbed the stool and the water upon it of so much heat that the water froze. Perhaps you thought that it was the fire which melted the snow in the mug, and you wondered why, if it was so hot, the water on the stool should freeze. The fire did its best to prevent the freezing, but the chilling went on too quickly for it, and as to the snow and salt, they would have melted if the fire been a hundred miles away. Your father tin mug rather than an earthenware one,

because heat and cold pass more easily through tin than through crockery.

This mixture of ice and salt is the freezing mixture of which I spoke in my first letter. I don't wonder that Annie's fingers ached when she put them into it. If you plunge the thermometer in it, you will see that it is terribly cold. Confectioners collect ice in winter from ponds, and keep it till summer in a place built on purpose, so as to be very cool; then they put cream and other good things into a tin pail and plunge it into a mixture of ice and salt, and the cold freezes the cream. That is how 'ices' are made, such as you see advertised in the shop windows. I am afraid that is all I have to tell you about ice, for which I am sorry. It is a safe thing for you to meddle with,—no fear of your burning your fingers with it,—and one you can easily get, at least in winter. One thing more about it. Ice, just before it melts, grows rotten, and breaks very easily. So it is not safe to slide on a pond after the thaw has begun, even though the ice may be very thick.

I am afraid some of what I have been telling you to-day is difficult. All I can say is,

think about it, try the experiments, and then think again. I hope it will become clear in time.

Believe me your affectionate Aunt,
RACHEL.

IV.

My dear NED,

Are you ready for another of my long puzzling letters? If you are, let us go on heating the water in our saucepan after all the ice is melted. As soon as the thermometer in it has risen to about 40°, the water begins to take up more room, and from that time, the hotter it grows the more room it will take up. Therefore the hottest water floats at the top. If you put a piece of ice into a glass of hot water, you will see as it melts streams of cold water sinking from it to the bottom; or if you pour hot water *very* gently through a little pipe, or out of a bottle under the surface of cold water, you will see the hot water rise to the top. You must pour very gently to see this, or the force with which the hot ·r falls will send it to the bottom, in spite of

its lightness. It takes more heat to raise the temperature of water a certain number of degrees by the thermometer than is wanted for any other substance. I mean that we should have to burn more coal to make a pound of water one degree hotter than would be necessary to make a pound of quicksilver or spirits of wine one degree hotter. On the other hand, the water in cooling gives out more heat than the quicksilver or spirits of wine. It is said to have great '*capacity for heat.*' For this reason, islands are neither so hot nor so cold as continents. When the sun shines, or a hot wind blows towards them over the sea, a great deal of heat is taken up by the water. It is not quickly made as hot as the air about it, and in getting as hot it robs the air of a great deal of heat. One pound of water in growing one degree hotter makes four pounds of air one degree cooler. So you see the hot wind is not very hot by the time it reaches the land. Then, again, when the sun sets, or a cold wind comes, the water gives back to the air the heat which it had taken from it, four pounds of air being warmed one degree for every pound of water that is cooled one degree. The water is a sort of storehouse, taking in heat

when there is too much of it, and giving it out again when there is too little.

A thermometer in an open saucepan of water cannot rise higher than 212°. The water then boils, and more heat added to boiling water changes it to steam. Now the white cloud which comes puffing out of the spout of the tea-kettle is not exactly steam. Steam is quite transparent, and as invisible as air. Look more carefully at the kettle when it is quite on the boil, and you will see that the white cloud does not begin close to the spout, there is a space between. The real steam is in that space, and the white cloud is made by the steam getting so much cooled as it comes into the air, that some of it is changed back again into water. The cloud is made up of tiny drops. If you hold a cold bright spoon in the space where you see nothing, it will be dimmed with little drops quite as soon as if you hold it in the cloud which we generally call steam.

A great deal of heat is made latent when water turns into steam. You remember what is meant by that? I mean that a quantity of heat is stored up in the steam which cannot be discovered by the thermometer till the steam is *condensed*, that is,

changed back again into water. So that steam in which the thermometer stands at 212°, when it is condensed by coming into a cold place, turns into water at 212°, and gives out a great deal of heat besides.

Steam takes up a great deal more room than water. The quantity of water which would fill a square box measuring an inch every way would, when changed into steam, fill a square box measuring a foot every way. Or, to say the same thing in shorter words, a cubic inch of water makes a cubic foot of steam. So that if you were to stop up the spout of the kettle, the steam would blow off the lid to make room for itself. I think however you had better take my word for that, for I fancy your mother would not like your trying experiments of that sort. Some people when they bottle fruit cork up the bottles, and then put them in hot water over the fire. This is very dangerous, for, when the juice boils, its steam will expand as the steam of water does, and it is not at all unlikely to blow out the cork; then, if any one is standing near, they run the risk of getting terribly scalded. You remember how the freezing point of water is lowered by pressure—how, because water takes up

more room as ice than as liquid water, whatever tends to prevent it from expanding tends to prevent it from freezing. So that when water has no room to expand, it may be chilled below 32° without turning into ice. Something like this takes place when water boils. The boiling point is *raised* by pressure. If the water has not room to expand, it does not change into steam, even though it is heated above its boiling point. Water may be heated in strong close iron vessels far above 212°. It is very dangerous to do so, however, for the vessels will burst unless they are very strong indeed. If the pressure is suddenly taken off, a great quantity of water will pass into steam all at once with much violence.

Perhaps you will be surprised to hear that the air is always pressing upon us, upwards and sideways as well as downwards. We do not feel it, because it presses equally in *all* directions; but though we are not aware of it, it does press on every square inch of our bodies and of everything around us, with a force equal to 15 lbs. weight. It is very wonderful that this can be so without our feeling any inconvenience from it, or even knowing it, is it not? If the air is taken away from one

side of your hand (by a machine called an air-pump) you will feel the pressure on the other side. You may feel it a little when you suck some of the air away from the palm of your hand with your mouth. I have not time now to tell you about squirts and pumps and suckers and barometers, and all the wonderful things which show the pressure of the air. I want to tell you what effect it has on the boiling of water. It presses, as I have said, with 15 lbs. weight on every square inch of the surface of water, and thereby raises its boiling point. If the air did not press so heavily, water would boil at a lower temperature. The pressure on the surface of a vessel of water may actually be lessened by putting it under the 'receiver' of an air-pump, that is, a glass vessel which may be nearly emptied of air. The water will then begin to boil, though it may be far colder than its usual boiling point. At the tops of high mountains, too, the air does not press so heavily as it does in valleys, and accordingly, at the top of a high mountain, water boils at a very low temperature. At the top of Mont Blanc (which is the highest mountain in Europe, you know), water boils at about 184°.

However large a fire may be made under it, it grows no hotter, but boils away into steam. I don't think I should like to eat potatoes which had been boiled at the top of Mont Blanc!

When water boils, the greater part of the steam comes from the bottom of the pot in bubbles. But even in cold water a great deal of steam (or, as it is called in this case, '*vapour*') rises quietly from the surface, though from nowhere else. You know how water dries up, especially in hot dry weather. What do you think becomes of it? It 'evaporates' or changes into vapour. If you wet your finger, either in warm water or cold, and let it dry in the air, you feel a coolness. This is because the water on your finger is turning into vapour, and therefore a quantity of heat is made latent. This evaporation goes on more quickly in windy than in still weather, because the air which has been made damp passes quickly on, and fresh dry air touches the water. You know how quickly clothes dry when they are hung out in a wind. As evaporation goes on only at the surface of water, it is more plentiful in a wide flat vessel than in a tall narrow one. I suppose that this is why some old (and some little girls too, I am afraid) have

got the ugly trick of pouring their tea into their saucers, instead of waiting patiently till it is cool enough to drink properly out of their cups. Evaporation goes on more quickly too in hot weather than in cold, because hot air can hold more watery vapour than cold air can. There is always more or less watery vapour in the air, though it is so perfectly transparent that we cannot see it. Indeed, the air is often clearer than usual when it is very full of moisture; and when we can see much farther than usual, we consider it a sign that rain is not far off. When the watery vapour becomes chilled high up in the air (which often happens from various causes), a cloud is formed by the condensation of some of it. If the cold is very great rain falls, or even snow or hail. Almost all our rain comes from the south or south-west, because the winds which blow from those quarters come from hot countries, and get a great deal of moisture as they pass over the sea. As they come northwards to our colder land, they cannot keep all the moisture which they have collected, and thus we get the rain which makes England and Ireland so fertile and green. Our east and north-east winds, on the other hand,

hardly ever bring rain, because they come from colder countries to warmer, growing more and more greedy for moisture, till our very skin gets dry and cracks. This greediness makes the east winds all the colder too, for in the changing of so much water to vapour, an immense quantity of heat is made latent.

This letter is now quite long enough. In my next I will tell you something about Dew.

I am always your affectionate Aunt
RACHEL.

V.

My dear Children,

Do you remember how beautiful the dew was last autumn, when you were here? The days were fine and warm, the nights clear and rather cold, and when we went out early to feed the chickens all the grass sparkled in the sun, and every cobweb had its covering of tiny drops, looking like a diamond necklace fit for a fairy. I will try and explain to you something about the causes of all this beauty.

Perhaps you have noticed in very hot weather

how a bottle of water fresh from the well grows quite moist on the outside. This is because the bottle of water is colder than the air, and chills some of it so much that it cannot hold all the watery vapour which it held when it was hotter. So part of the vapour turns into liquid water, and wets the outside of the bottle. This wetness is much the same thing as dew.

Some things both get heat and lose heat more quickly than others. If you take two tin cans, alike except that one is bright and clean, whilst the other is blackened with smoke from the lamp, and fill them both with boiling water, the clean one will keep hot the longest. Sometimes, when one-half of the kettle has been coated with soot, while the other half was bright and clean, I have held my hand an inch or two off, and distinctly felt that more heat came from the dirty part than from the clean. So you see that you must take care that the kettle is bright, and not covered with smoke and soot, if you want it to keep hot after you take it off the fire. A metal tea-pot, too, will keep the tea much hotter than an earthen one. Perhaps you think that this contradicts what I said about heat passing more easily through metal than

through earthenware; but the facts are so, and there is no real contradiction. I believe the metal tea-pot does lose rather the most heat in one way, but the earthenware very much more in another. You would be more likely to burn your finger by touching the metal tea-pot, but if you hold your hand an inch or two from it, you will feel the most heat coming from the earthenware. The metal loses more heat than the earthenware does by what is called *conduction*; that is, by touching some cold solid thing: but the earthenware more than makes up for this, since it loses a great deal more than the metal does by *radiation*. That is, it sends out rays of heat which pass through the air and are drunk in by the first solid or liquid thing on which they fall. Those things which drink them in most readily also lose them most readily.

Grass is one of the things which both gets heat and loses it quickly in this way. In the day-time it is heated by the sun till it is much hotter than the air about it. On fine clear nights in exposed situations it loses this heat as fast as it had gained it, and grows much colder than the air. Then just the same thing happens as in the case of the jug

of cold water. In the day-time the air had been taking up watery vapour from every moist thing it could get at, till it had got as much as it could hold. In fact, it was soaked, or *saturated*. When it touches the cold plants at night it cannot hold all its moisture, for you remember that it cannot hold nearly as much when it is cold as when it is hot. So the vapour condenses, and is laid gently in tiny drops on the leaves.

On cloudy nights there is little or no dew, because the clouds keep the earth warm. It is very wonderful that they should do so, being so high up, is it not? On cloudy nights the grass is sometimes even warmer than the air. The reason is, that on clear nights the grass sends its rays of heat up into the open sky and gets none back again, whereas when the sky is covered with clouds they are warmed by these rays and send back heat to the grass.

People used to have very mistaken notions about dew. Many thought that it rose up from the ground like steam. At last, a gentleman named Dr. Wells made a number of experiments about it, and found out all that I have just been telling you. He used pieces of cotton-wool to collect the dew,

weighing them before he put them out at night, and again in the morning, so as to measure by weight the quantity of dew they had gained. By the side of the wool he put thermometers, and found that the places where there was most dew were also the coldest places. He supported a piece of board about two feet from the ground, and put some wool and a thermometer upon it, and more wool and another thermometer under it. The wool upon the board got more dew than the wool under it, and the thermometers showed that it was colder upon the board than underneath it. Can you tell why this was? The wool and the thermometer upon the board sent their rays of heat into the open sky and lost them, whilst the wool and the thermometer underneath sent their rays only as far as the board, which was warmed by them and sent some of their heat back again. This experiment showed that dew did not rise from the ground, since, if it had done so, the wool on the ground would have got more than that on the board.

The very slightest covering will check the chilling by radiation and so lessen the quantity of dew. I have seen the gardener at Mr. Neville's read a thin piece of gauze over a flower-bed

when he expected a hoar-frost, and was afraid of his flowers being hurt by it. He said, that if it was only a slight frost, that stuff, though it was so thin, would keep the heliotropes quite warm and safe. It prevented them from getting much colder than the air. Of course, if it were cold enough for the *air* to sink below 32°, the plants would suffer in spite of their covering. The Miss Nevilles give their thin ball dresses to the gardener when they are old and dirty on purpose to protect the flowers.

Now I will tell you about what I think is the most beautiful provision that I know of connected with this beautiful thing, Dew. You remember what I told you about the quantity of heat which is made latent when water turns into steam or vapour, and how that heat is given out when the vapour turns into water again. As the watery vapour of the air is turned into dew it gives out heat, so that the leaves are actually warmed by the little sparkling drops which cover them. If it were not for the heat thus given out, plants would be injured by cold much oftener than they are. When the nights get colder and colder, so that, in spite of the dew, the grass is chilled below 32°,

then the dew freezes, and we call it hoar-frost. And here again we see the same care for the plants. You know that the latent heat of water is given out when it freezes, just as the latent heat of steam is given out when it condenses. Thus the air about the plant is warmed first when the vapour changes to dew, and again when the dew changes to hoar-frost.

Some people seem to think that learning how these things come to pass takes away from the pleasure and beauty and poetry which one finds in them. I cannot think so. A child may perhaps like his toy less when he finds out how ugly the machinery is which moves it, but it is not so with the things which God has made. They are perfect in every part, and the more we look into them, the more beauty we shall find there. We shall find beauty in what we thought was meant only for use, and use in what looks like mere ornament, for I believe that God has made nothing either ugly or useless. And surely we shall not love and admire beautiful things any the less for knowing that, like everything else, they have a work to do in God's world.

Believe me your affectionate Aunt,

RACHEL.

VI.

My dear NED and ANNIE,

I am glad to think that this will be my last letter for a long time. It is all very well to write letters when we are a long way apart, but it is better still to have my little helpers with me in the garden and dairy and chicken-yard. But I want to finish what I have to say about water, so I will not waste time by talking about other things.

What is Water made of? That is what we must consider to-day. Perhaps you are surprised at the idea of water being 'made' of anything. You think water is water, a thing by itself, which we cannot pull to pieces and separate, as we separate milk into curds and whey, or cream into butter and buttermilk. So wise men thought for many years; but they found out at last that they were mistaken. Water is made up of two simple substances, which cannot be further divided. They have long names, I am sorry to say, but we must remember them, Oxygen and Hydrogen. They are not liquids, as you might expect, but gases as clear and invisible as air.

You could not see any difference between a bottle full of air and bottles full of oxygen and hydrogen, by merely looking at them. If you weighed the two bottles in scales, however, you would find that containing the hydrogen the lightest. Hydrogen is the lightest of all known substances. Is it not strange that these two air-like gases should make up water when they are joined together, 'combined' or 'united,' as we call it? I have seen them made to combine. They were mixed together in a jar, but mere mixing did not make them unite. A lighted spill was put to the mouth of the jar; there was a flame for a moment, a very loud sudden explosion, and then the great jar was found to be emptied of the gases, and its sides were wet with water. There were only a few drops, for it takes a great quantity of the gases to make a very little water, they take up so much more room before they combine than they do afterwards.

In this experiment large quantities of the gases were used, and we were startled by the violence of the explosion; yet every day oxygen and hydrogen are combining before our eyes, quietly, noiselessly and constantly, a little at a time, without

our thinking anything about it. I must tell you something about their properties.

Hydrogen will burn in air and oxygen will not, but anything which will burn in air will burn more brightly in oxygen. In fact, when we say that anything is burning, we almost always mean that it is uniting with oxygen. When a candle burns, it is something in the candle, uniting with the oxygen in the air, which makes the light and heat. The air is made up in part of oxygen mixed with about four times its own quantity of another very sluggish gas, which will neither burn itself nor help other things to burn, at least in ordinary circumstances. In pure oxygen, iron and steel burn as wood and coal do in the air; and a candle with only the snuff alight flames up brightly when plunged into a jar of oxygen. So you see the sluggish gas which makes up the greater part of the air is of the utmost use to us, for if the air were made of oxygen alone, fire would indeed be our master instead of our servant (and there is a proverb which says that fire is a very bad master), not to speak of other consequences which would be even more fatal to us. When a candle burns, the light is caused chiefly by what is called

'carbon' in the candle, uniting with the oxygen of the air. Besides this carbon, there is hydrogen combined with it in the candle, and in the heat of the flame this hydrogen combines with the oxygen of the air, and forms water, which passes away as steam without our noticing it. Hold a clean bright spoon over the flame of a candle, and it will be dewed by the steam which condenses against its cold surface. If you put a lump of ice into the spoon so as to prevent it from being heated, you may condense so much water on the under side that a drop will fall on the candle and put it out.

There is a most wonderful and beautiful likeness between the burning of a candle and the way in which we breathe. When we draw air into our lungs, it meets with blood which has become impure by passing through the body. This blood, like the fuel of the candle, contains carbon and hydrogen, and these unite with the oxygen of the air, in our lungs. Thus the blood is purified and the heat of our bodies is (for the most part) caused. Even in hot summer weather the air in the shade is not so hot as our bodies. The air which we breathe out from our lungs is just like

the air which rises from a candle. Both are unfit to breathe. If we breathed much of either, unmixed with fresh air, it would kill us. Both, if unmixed with fresh air, would put out a lighted candle. Both, too, are hot and moist. You know how a glass becomes dimmed with little drops when you breathe on it, and how in frosty weather a little cloud of steam rises from your lips. That steam is caused by the oxygen of the air uniting with the hydrogen of your blood, in your lungs. Thus you see we have a sort of fire always burning inside us, which keeps our blood as hot in winter as in summer. We *feel* as if it must be colder at some times than at others, but a thermometer placed under the tongue shows very nearly the same temperature in all weathers.

Now I think I have finished all that I can tell you about water. I should have liked to say something about the way in which water is separated into oxygen and hydrogen, by means of an electric current, but I am sure I could not make it clear to you, and, rather than give you a confused idea about it, I will leave it alone.

Perhaps you wonder what *use* it will be to you to learn about these things. For my part, I find

it such pleasant work, that I should like to do it in my spare time, even if it were of no use. It makes one so much more happy and contented to have something to think of, quite apart from oneself. Of course, if we spend time and thoughts upon it which ought to be spent on duties, it must do us harm, but otherwise, I think it helps us to realise that God is always near us, compassing our path. When I was your age, I used to think that God created the world in the beginning like a great machine, so that it would go of itself without any further guidance from Him; but when I began to learn about the 'fire and hail, and snow and vapours, and the stormy winds fulfilling His word,' it seemed to me rather that He was every minute creating the world afresh,— guiding every atom in all its changes. This world is such a living, changing thing! Not only plants and animals, but those things which we generally think of as lifeless, are continually changing. Ice turns into water, and water into steam, by each change altering the heat of what is near it, and in many ways which I can't stop to explain (some of them you may think of for yourselves) causing change all around it. Of course we all

know that God is always with us; but it is one thing to know it in our minds, and quite another to *realise it,* by feeling it in our hearts; and when we have learnt to look at the beautiful shapes of the snow-flakes, and the sparkles of the dew, I think we shall find that they remind us how near our Father is to us, and how careful He is of the smallest thing which He has made. Perhaps it is not too much to say that we are not likely ever to go very far wrong as long as we really remember that.

Now, dear children, good-bye, and believe that I am always

Your affectionate Aunt,

RACHEL.

PART II.

(*From Ned to Aunt Rachel.*)

Dear Aunt RACHEL,

Now that we've come home again, we want you to write us some more letters, and I've got a question to ask you. You know the new pump which was put up at the end of our street when you were here three years ago? Well, it has gone very dry every autumn; so, at last, they've been digging the well deeper, and they've taken away the old pump, though it was just as good as new. Father asked one of the workmen why they did it, and he said the well was more than thirty-three feet deep now, so they had to make an alteration in the pump. So, please, will you tell us about pumps. Annie has another question to ask. She wants to know all about the fire-balloons which we saw the night of the illuminations, when the Princess was married, and why they went up into the air?

Your affectionate Nephew,

NED.

I.

(*From Aunt Rachel to Ned.*)

My dear NED,

Your questions will take more than one letter to answer. Before I can answer either of them, I must tell you several things about Air.

When we talk of a thing being as light as air, we don't mean that it weighs nothing. If we were to weigh a bottle, out of which the air had been taken, by means of a machine called an air-pump, we should find it lighter then than when we had taken out the stopper and let the air in again. A pint of air, at the earth's surface, weighs between ten and eleven grains. Why do I say 'at the earth's surface'? I will explain. The air is supposed to stretch up at least fifty miles high, forming a shell to our round earth certainly not less than fifty miles thick. But the little particles of air are crowded much closer together near the earth than they are higher up; or, as we say, the air is much *denser* low down, and *rarer* high up. The quantity of air which would fill a pint bottle at the height of five miles from the earth would

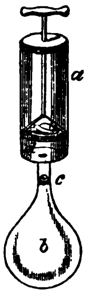
not weigh nearly ten grains. If you were to pile twenty feather beds one on another, the lowest would be pressed into a small space by the nineteen on the top of it; the next would be rather less pressed, and so on to the top one, which would not be crushed at all. Perhaps the lowest ten might take up little more than half the room that those above them do. It is just so with the air. That near the earth has the weight of all the fifty miles above it, crushing it together, and so much less room does it take up in consequence, that if a line were drawn as high as the tops of the Himalaya mountains, the air below that line would weigh as much as the air above it. As much air is crowded into the lowest six miles as is spread over the forty-four miles above, and this is caused entirely by the weight of the air in the upper regions pressing on that in the lower regions. We do not know how much further than fifty miles the air may extend, but we do know that if we were to empty a bottle of air as thoroughly as we could by means of an air-pump, the small remnant of air left in it would still be denser than the air fifty miles from the earth. If ould *fill* a bottle with air at that height, it

would have less air in it than the bottle which we had emptied (so far as this is possible) with an air-pump at the surface of the earth.

Every square inch on the earth's surface has a column of air resting on it at least fifty miles high, and pressing on it with a weight of fifteen pounds. I told you this in one of my old letters; but, until one has been used to the idea for a long time, it is difficult to believe it. It is so extraordinary, is it not? that we should have a pressure of fifteen pounds on every square inch of our bodies, and yet not be aware of it! One would expect such a weight to crush us to death; and so it would, if the pressure were only in one direction, but the air is all around us, and presses equally in every direction, upwards as well as downwards, inside our lungs as well as outside. If you stretch a newspaper screen across your room, fastening the ends firmly to the walls, and then if you lean against it on one side, and Annie exactly opposite, on the other, the screen will not be torn; but if Annie were suddenly to jump away, you would burst through the paper and fall on your back. So, as long as we have the air pressing about us in all directions, we do not feel it, but if we

could take away the air from one side we should feel it very plainly.

Once, when I was at school, a gentleman brought an air-pump to show us, and I wish I could show you all the curious things I saw then. Let me try and explain to you something about the air-pump. You know very well what a syringe or squirt is like. Imagine a syringe (*a*), fastened at its lower end to the neck of a bottle (*b*), and, instead of a cork in the neck, fancy a little valve (*c*) opening upwards. A valve means a little door, which opens only one way; so that, in this case, anything inside the bottle could get out by pushing, but anything outside would only shut the valve firmer the harder it pushed. If you want to see a valve, look at the bellows, and you will find one in the side where the air enters. Just such another little valve is in the piston of the syringe, at *d*. When the piston is raised, the valve *d* is shut tight by the air above pressing against it, so that none of the air in the



-r part of the syringe can get into the lower
-nd the pressure is taken off the air in the

bottle; so the air in the bottle, being elastic, expands, pushes open the valve *c* in the neck, and fills the part of the syringe below the piston. Then, when the piston is pushed downwards, as represented in the illustration, so as to compress the air below it, the valve *c*, in the neck, shuts, and that in the piston opens, and the compressed air escapes into the upper part. Raise the piston again, and the air remaining in the bottle expands to fill the space below the piston, ready to escape through *d* when the piston is pushed down again. Thus the bottle, at last, gets nearly emptied of air. The air is always spread over the whole bottle, but it becomes more and more thin, or *rare*, as it is called.

This is called an '*exhausting syringe*,' and when any vessel has had the air removed from it, it is said to be exhausted, and to contain a 'vacuum,' which means an empty space. It is not really quite empty, for it is impossible to take away the whole of the air. Now, the air-pump has two exhausting syringes, the pistons of which are worked by one handle. Both syringes end in one tube, which comes out at a hole in the middle of a flat brass plate. Over this hole is put what

is called the 'receiver,' a round glass shade, made very strong, in order to resist the pressure of the air outside it, when there is none left inside to press back again. The edge is well greased where it touches the plate to prevent any air getting in there, and then, when the syringes are worked, the receiver is exhausted. Sometimes a receiver is made with a hole in the top, which is stopped up with anything which we wish to examine while the air is pressing upon it.

The first thing which we examined in this way was my hand. I covered the hole with it, and, as soon as the gentleman began to work the handle slowly, I began to feel an odd, unpleasant feeling. As soon as my hand was pressed upon less by the air in the receiver than by that outside, I felt as if the flesh of my hand was being sucked in; or, to speak more correctly, the outside air pressed it in between the bones, so that the back of my hand looked frightfully thin. In a little while this grew so unpleasant that I tried to pull my hand away, but I could not do it without hurting myself; and there I was a prisoner, till a little cock was turned, so as to let air into the receiver again.

Then a bladder was tied over the top of the receiver, and the air pumped away from underneath it. It began to bulge inwards more and more as the pumping went on, till at last it burst with a loud crack. It was not strong enough to bear such great pressure. Then a wooden cup was fitted into the opening, and the cup filled with quicksilver. After working the pump for some time, the pressure on the quicksilver was so great that it was forced through the pores of the wood, first in a few trickling drops, then in a silver shower. We next took a receiver which was closed at the top, instead of the one with an opening, which we had been using; put a withered, shrivelled apple under it, and began to pump. The skin of the apple began to swell out, and soon it looked as round and smooth as it did on the tree. The reason was that the air *inside* the apple expanded and pressed its skin outwards, as soon as the pressure of the air *outside* was lessened. Of course, as soon as the air was let into the receiver again, the apple shrivelled up.

You can do none of these things yourselves, for want of the proper apparatus; but there are several easy ways of showing the pressure of the

air. If you clap a shilling quickly and firmly against the shutter, so as to drive out the air from between it and the shutter, the pressure of the air outside will keep it from falling, and it will stick there some time. A fly's foot is so made as to drive away the air from behind it, and thus the pressure of the air enables the fly to walk on the ceiling. I dare say Annie will remember how I disliked the popping noise she used to make with her thimble when she was tired of sewing. This was caused by the air rushing in suddenly to fill a vacuum in her thimble, which she had made by taking her finger out. If she stops short just before the pop, having taken the end of her finger out of the thimble, but still stopping up the entrance, the pressure of the air will hold the thimble to the finger in spite of a vigorous shake. Or you may fill a wineglass quite full of water, cover it with a card, and turn it carefully upside down, holding the card in its place as you do so. When you have got the glass bottom upwards, the air will keep the card in its place, and prevent the water from running out. Or dip glass tube into a basin of water. The water rise in the tube to the same level as that in basin (or, indeed, a little higher, owing to

what is called 'capillary attraction' between the glass and water; but that does not concern us now). Put your finger on the top of the tube, and lift it out of the water. Your finger keeps off the pressure of the outside air at the top, while the pressure at the bottom keeps the water in the tube. Take your finger away. Now the pressure at the top and bottom is equal, and the water falls by its own weight.

In my next letter, I will answer your question about pumps.

From your affectionate Aunt,

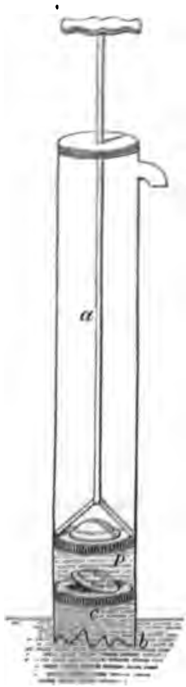
RACHEL.

II.

My dear Children,

In my last letter I told you how the air pressing upwards against a card can keep it in its place under an inverted wineglass full of water. Now lower the wineglass till the mouth is below the surface of some water in a basin, and take away the card. The water in the glass does not fall, because the air pressing on the water in the basin supports that in the glass. A bottle with

a narrow neck may be turned upside down in the air, if the neck is narrow enough to prevent any air from pushing up into the bottle to take the place of the water. A common wide-necked bottle would have two streams, —one of water, running out, the other of air, pushing in.



What happens when you suck water through a straw? You take away air from the inside of the straw with your mouth, and so the air outside, pressing on the surface of the water, pushes it up the straw. Just the same happens when you fill a squirt with water, the only difference being that you draw the air out by pulling up the piston, instead of by sucking with your lips.

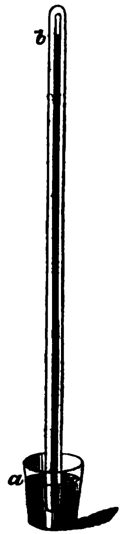
This is the principle of the 'suction-pump' which no ubt is the sort that was first put up in your eet. A pipe (*a*) dips into the water (*b*) in the

well, with a piston (p) fitting into it. There is a valve in p, and another at c, both opening upwards. When the air is drawn out of the pipe, the water is forced up it by the pressure of the air on the surface of the water in the well. When the piston is lowered again, the water cannot make way for it (for the valve at c shuts by its own weight directly the water stops pressing upwards through it), and forcing open the valve at p, it rises above the piston. When the piston is raised again the water is lifted with it.

This fact has been known for many hundred years, but the cause was not understood till rather more than 200 years ago. Nobody had found out that there was any weight in air, and they explained the fact by saying that 'Nature abhorred a vacuum.' If they had been called on to explain their explanation, perhaps they would have been puzzled. At any rate, they were very much puzzled when some Italian workmen, in deepening a well, found that the water would not rise to the spout of the pump. It rose in the pipe for about thirty-two feet above the water in the well, and then it stopped. Above that there was a vacuum. Of course if the water had once risen above the

piston, it could be lifted to any height; but when the piston was more than thirty-two feet above the surface of the water,—when the distance between *b* and *p* was more than thirty-two feet,—the water would not rise up to the piston. They asked the reason of a wise man who lived near, and whose name was Galileo. He invented telescopes and discovered many wonderful things, but for some reason he did not pay much attention to what was said to him about the well. Perhaps it might be because he was busy about something else, perhaps because he was old and ill. Whatever was the reason, he gave them a joking answer, that 'Nature's abhorrence of a vacuum extended only to thirty-two feet.' But a pupil of his, named Torricelli, thought more about the matter. At last, it struck him that the water was forced up into the pipe only by the pressure of the air upon the surface outside, and when the well was so deep that the pressure of the water in the pipe was as great as the pressure of the air outside, the water would rise no higher. Since vas found that water would rise no higher than ty-two feet, it followed that the weight of air must be equal to the weight of thirty-two of water. He began to think how he could

test this idea of his, and he thought that if he took a liquid heavier than water, a column of that liquid less than thirty-two feet high would have a pressure equal to that of the air. So he took quicksilver, which is very heavy, compared its weight with that of water, and found it about thirteen times as heavy. From that he calculated the height of a column of mercury which should weigh as much as thirty-two feet of water. Then he took a glass tube, closed at one end, and a little longer than he expected to want. This he filled with mercury, and put his finger on the open end, while he carefully turned it bottom upwards with its mouth in a cup of mercury. To his great delight, the mercury fell a few inches, and then fell no more. Water would have been supported in such a tube to the top, but quicksilver was too heavy to be supported by the pressure of the air above a height of about thirty inches. The distance from the surface of the quicksilver in the cup (*a*) to the surface of that in the tube (*b*) was thirty inches,—the very height that his calculations had led him



to expect. Above thirty inches was a space which was for some time believed to be a perfect vacuum. Now it has been found to have a little vapour of mercury in it.

A column of mercury, one inch square at the bottom, and thirty inches in height, is equal in weight to a column of air one inch square, and the height of the atmosphere, whatever that may be. This column of mercury is a barometer.

It was soon found that its height was not always exactly thirty inches. Sometimes it was a little more, sometimes a little less, owing to currents in the air, which make the pressure sometimes more and sometimes less. Then it was found that a fall in the barometer was apt to be followed by rain or high wind, and the instrument began to be used as a weather-glass. But to this day people do not know much about the weather and its effect on the barometer.

Although Torricelli himself felt pretty sure that his explanation of pumps was the true one, he failed to convince every one that it was. If the air *had* weight, they said, no doubt it would support columns of fluid in the way that Torricelli said, but he had not proved that it had any weight. At

last an experiment was made by a great and good Frenchman, named Pascal, which, as he expected, settled the question once for all. His idea was this.

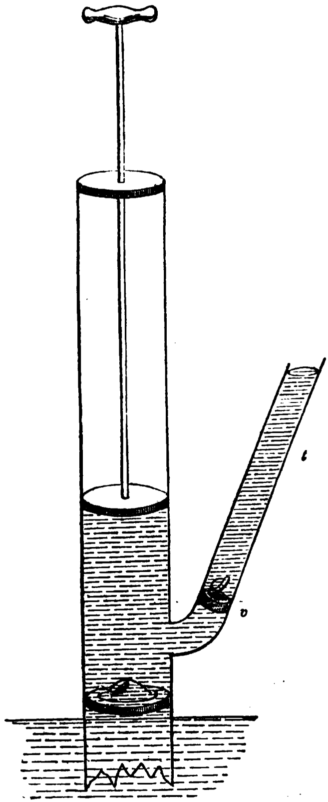
If the pressure of the air is able to support mercury to a height of thirty inches at the surface of the earth, when we go up a mountain, and have less air above us, the mercury ought to fall, because the pressure will be less. You know, from what I told you about the greater density of the air near the earth, that a considerable part of the air is left behind when we go up even a moderately high mountain. Pascal tried his experiment on the Puy de Dome, in Auvergne. He carried one barometer up with him and left another at the foot of the mountain with a friend, who promised to watch any change in the height of the mercury which might happen to take place from a change in the weather while the ascent was being made. As Pascal went up the mountain he saw the mercury falling continually till he reached the highest part, and as he came down it rose again. He was nearly sure now that he had succeeded in proving the truth of Torricelli's explanation, and when he found from his friend that the barometer

in the valley had been stationary during the whole day, he was quite sure of it.

Of course the barometer will fall when the pressure of the air is lessened, from whatever cause. It is customary to have a barometer connected with good air-pumps, in order to be able to tell exactly how much the air in the receiver is rarefied.

The change that was made in your pump may have been merely that a longer handle was put to the piston so as to bring the piston-valve within thirty-two feet of the water. Or a 'forcing-pump' may have been put in its place. This pump has a side-tube *t*, with a valve *v*, and the piston has no valve. So when the piston is pressed downwards (as it is drawn in the illustration) the water cannot escape above it, but passes into the side-tube, and cannot get back through the valve *v* when the piston is raised again. At each stroke of the piston, therefore, more water is forced into the tube *t*.

But neither in this nor any other sort of pump can water be raised *by the pressure of the air* to greater height than thirty-two feet. That is, distance between the piston and the surface water must not be more than thirty-two



feet, though the strength used in pressing down the piston may force the water to a much greater height in the side-tube *t*.

Did it ever happen that your pump seemed to have gone altogether dry till a jug of water was poured down it, and then you could pump as much water as you liked? It has happened more than once to our pump here, and I should not wonder if you could find out the explanation of it. Will you try?

Believe me your affectionate Aunt,

RACHEL.

(*From Ned to Aunt Rachel.*)

Dear Aunt RACHEL,

Once I had an old squirt, and it lay in my drawer ever so long without my using it, and when I took it out at last it was spoilt. The handle went up and down too easily, and the water wouldn't come into it. When I showed it to father, he took off the top and poured a little water on the top of the piston. He said it had got shrunk with lying by dry so long. But though the piston was shrunk, it was still too big for the water which we poured in to run through easily, so that it filled up the space between the piston and the side, and prevented any air from getting in, and as soon as the piston got well wetted all over, it swelled out and was all right again. Is this the answer to the question you asked about your pump? If the piston didn't fit well, would not pouring down water make it act?

Your affectionate Nephew,

NED.

III.

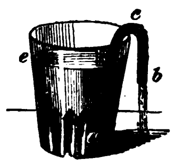
(*From Aunt Rachel to Ned.*)

My dear NED,

Your answer about our pump was quite right.

I am afraid you must have found my last letter a dull one, because it was all about what learned men did long ago, and told you nothing to do for yourselves now. I will try and make up for that in this letter.

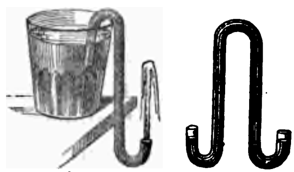
Get a few inches of flexible india-rubber tubing. Put one end (*a*) into a jug of water, and let the other end (*b*) hang down over the outside, lower than the level of the water in the jug. Put your mouth to the end *b* and suck away the air. The water will be forced up to fill the tube by the pressure of the air outside, and will go on running till the water in the jug falls as low as the outer end of the tube. This sort of bent tube is called a siphon. Perhaps you wonder why it should go on running, seeing that the air presses up at *b* in the contrary direction from what it does in the



other end of the siphon. In fact, a struggle is going on, and a drop at *c*, the top of the siphon, is pushed in two directions by the two opposite forces, but they are not equal to each other. The air at *b* spends some of its strength in supporting the water between *b* and *c*. So, too, the pressure on the water at *e* is partly spent in supporting the water between *e* and *c*, but less than in the other leg, because the distance between *e* and *c* is shorter than between *b* and *c*. So the force which drives our drop at *c* outwards is stronger than that which drives it inwards, and the water goes on flowing. When the water in the jug has sunk to the level of *b*, it will stop flowing. Why? Because the distances between *b* and *c* and between *e* and *c* being equal to each other, our drop at *c* is driven outwards and inwards by two equally strong forces, so that it stands still. If you move the siphon so that *b* is once more below the level of the water, the stream goes on again; but if you tilt it the other way, so that *b* is ever so little above the level of the water, the pressure at *b* triumphs over its rival, and drives the water out of the siphon back into the jug. Then you will ve to suck the air out once more before you

can set it off again. Or (as india-rubber is not very pleasant to put into your mouth), you may plunge the whole tube in water, so as to fill it, stop the two ends with your fingers, and then set it going.

Or you may make a glass siphon. You can buy a bit of glass tube for a penny or two at a chemist's, and you may bend it into any shape you like in a candle. Only you must do it carefully, lest by heating it too suddenly you should crack it. The best way will be to hold it a little above the flame at first, and lower it slowly, turning it round and round all the time so as to heat it equally on all sides. If you turn up the outer limb of your siphon, thus (A), the water will be forced up in a little



A B

fountain. Or you may make a siphon, which, once full of water, will be always ready for use, this shape (B). Only you must keep it upright, because, if you tilt it, it is the same thing as making one leg shorter than the other. On the whole, I think you will get a good deal of amusement out

of the siphon. No doubt you have often made something of the siphon kind without knowing it. When you have put flowers in water, have you not sometimes been surprised to find the table wet, though you were sure you had spilt no water? Perhaps you wiped it up and went away, but when you came back the wiping had to be done over again. Then you noticed that water was dropping from one of the leaves which overhung the edge, and when that was tucked back the dropping ceased. Or, if you leave a towel hanging over the edge of a basin with one end in the water, you are not unlikely to find the basin half emptied by this siphon. In these cases it is not, however, the pressure of the air which forces the water up the towel and along the leaf, but 'capillary attraction.' It is the same thing which makes a sponge suck up water, and blotting-paper soak up ink, and which is very strong in the narrow passages between the threads of the towel.

One more instance of the pressure of the air. You have often helped to make currant tarts, and have put an empty pudding-cup bottom upwards amongst the fruit. When the tart is ready to eat,

the juice, instead of running about the dish, in danger of being spilt, is chiefly hidden away under the cup, waiting till that is lifted up before it runs out. How does the juice get into the cup, and when it is in, what keeps it there? I will tell you. When the tart is put into the oven there is nothing but air in the cup. As the air grows hot, it expands and lifts up the cup sufficiently to let a bubble of it escape. This goes on till most of the air in the cup is driven out. When the tart is getting cool, the little air that is left in the cup gets cool too and contracts, and the outside air pressing on the juice in the pie-dish forces it up into the cup to take the place of the air which has escaped. So this common bit of cookery is an example of one important fact which we have been talking about—the pressure of the air, and of another important fact, about which I will tell you something in my next letter, I mean the expansion of air by heat. And this will lead us to Annie's question about the fire-balloon.

IV.

My dear Children,

You remember that hot water is lighter than cool, because (after it has reached a certain temperature) the more it is heated the more it expands. Air expands with heat, too, and much more than water. Water, you know, does not expand at all temperatures. When it is solid ice, heat makes it melt and contract instead of expanding, and the same is true for a few degrees above the melting point. But air expands regularly from the lowest to the highest known temperature. If you had 490 pints of air at the temperature of freezing water (which, as you know, is marked 32° on our thermometers), and if you heated it to 33°, it would expand to 491 pints. If you chilled it to 31°, it would contract to 489 pints. For every degree of your thermometer which you heated it, it would take up more room, by exactly one four hundred and ninetieth part of the room which it took up at the temperature of freezing water; or for every degree that you cooled it, it would shrink just so much. As the air expands, it of course grows

lighter and rises, as hot water rises from the bottom of a saucepan to the top. When you open the door of a hot room, the hot air will make its way out at the top of the door, and cold air will pass in at the bottom to take its place. If you hold a candle at the top, the draught will blow the flame outwards; if at the bottom, the flame will be blown inwards, while you may find a spot between the two where there will be no draught, and the flame will burn steadily. This is why we should open the window both at the top and the bottom when we want to air a room, so as to let the hot, bad air out at the top, while the cool, good air comes in at the bottom.

I will tell you an easy way of proving to yourself that air expands with heat. Take a flask or a long-necked bottle, and place its mouth in a basin of water, whilst the greater part of the bottle projects over the edge of the basin.

Warm the air in the bottle by putting a candle underneath it, and bubbles will force their way through the water from the mouth. Take care not to crack the flask by

heating too quickly. Perhaps the tea-kettle would be a safer instrument to use, if you have one small enough to be heated by a candle.

Now at last we come to the fire-balloon. A piece of cotton-wool dipped in spirits of wine is placed on a bit of wire at the open mouth of the balloon. When it is lighted, heated air rises from it to the top of the balloon and fills it out, while cool air passes in at the bottom, becomes heated, and rises also. When the balloon is completely filled with air, which is hotter and lighter than that outside, it begins to rise, as a piece of cork would rise if you put it at the bottom of a jug of water. As the air grows hotter still, some of it is driven out at the bottom, thus further lightening the balloon. If it keeps upright, so that its sides do not catch fire, it may rise to a great height.

Why do you think smoke goes up the chimney? The blacks fall afterwards, as you who live in a town know to your cost, so it cannot be that they are lighter than the air. It is the hot air which rises with such a strong draught that it blows the blacks along with it, as the wind blows dead leaves about.

You know how near to the side of a candle you may hold your hand, and hardly feel any heat, while if you hold it over the candle at some distance you are soon glad to take it away. That is because the hot air rises from the candle. You may actually see it rise, if you put a candle in strong sunlight; a shadow of the flame will be cast on a sheet of white paper held behind it, and what looks like a shadow of the invisible air rising from the flame; because this air, being unequally heated in different parts, makes the light fall unevenly on the paper. Or on a hot summer's day you may see the heated air rising from a wall on which the sun is shining. Looking through it you see 'the landscape winking through the heat,' the unevenly heated air making everything beyond it seem to quiver.

You know that the sun shines more constantly and with greater power on the parts of the world near the Equator than anywhere else on our earth. Both land and sea there are hotter than they are here, and (like a brick wall in the sunshine) heat the air above them. Thus, hot air is continually rising up in these hot countries. Cool air flows from the Poles to the Equator to

take its place, as a cold draught comes under the door in a room where there is a fire. The hot air moves from the Equator to the Poles at a great height, as a hot draught moves along the ceiling and goes out by the top of the door. We will talk first of the cold draught at the surface of the earth.

If the earth were quite still, there would be a north wind from the North Pole, and a south wind from the South Pole, meeting at the Equator. But you know that the earth spins round like a top, or, in learned language, turns on its own axis, from west to east, once in every twenty-four hours, so that anything—a man, let us say—at the Equator, moves eastward at the rate of rather more than 1,000 miles an hour. Of course the man knows nothing about it, any more than you are aware of the fact that you in England are moving eastward too, not indeed so fast as our friend at the Equator, but still nearly ten times as fast as the fastest train you ever travelled in. A man at either of the Poles would have no motion of this sort. You may see this if you run a knitting-needle through an orange to represent the earth, and make an ink line round the orange

for the Equator. Make one little dot near the Equator to represent an African negro or a native of Peru, and one near the knitting-needle for an Esquimaux. You will see, as you look down upon them how much farther the man at the Equator has to move, when you turn the orange round, than the man at the Pole. If he were quite at the Pole, that is, on the tip of the knitting-needle, he would not move at all. Of course, when I speak of the knitting-needle representing the pole of the earth, I do not mean that there is really anything of the kind sticking out of the earth. You have learnt enough geography by this time to know that.

Now, while one of you turns the orange from west to east, let the other draw a line from the North Pole to the Equator, not moving the pen from west to east with the orange, but merely drawing it straight down from the knitting-needle to the ink-line. But as the orange is moving all the time, the line you have made in this way will not be a straight line. The point of your pen, instead of travelling straight from north to south, will, by the time it reaches the Equator, seem to come from the north-east.

Now, your pen represents a cold wind which starts straight southward from the North Pole. It has no motion towards the east, because the earth has none at the Pole, where the wind started. So when it reaches southern parts, where the earth turns round quickly *towards* the east, the wind seems to be blowing *from* the east. When you are in a railway-train, you know there seems to be a strong wind meeting you, whichever way you are going. It is really you who are moving, not the wind. Rain-drops, too, though they may be falling quite straight down, make a slanting line on the carriage-window, as if they had come from the direction in which the train is going. Just the same with a man who is standing a little north of the Equator. It is really he who is moving towards the east; but he is not aware of his own motion, and when he meets the wind which is blowing nearly straight towards the south, he says it is blowing from the north-east, and calls it the north-east trade-wind.

Now draw a line from the South Pole to the Equator, still keeping the orange turning and the fixed as before. Your pen will travel along

the orange to the north-west, and represents the south-east trade-wind. (You must remember that we call the winds after the quarter *from* which they come, not that *towards* which they are travelling.) These trade-winds are very constant on each side of the Equator, for a certain distance. By the time they reach the Equator, they have rubbed against the earth for so long that they have taken some of its motion, and begin to move eastwards too. When they are heated and rise up to take their journey towards the Poles as the 'Upper trade-winds' this motion begins to show itself. While they were travelling from the Poles to the Equator, they were moving from parts of the earth which have little motion to those which have a great deal. But now, when they move as an upper current from the Equator to the Poles, just the contrary takes place, and the winds seem to blow from the south-west in the northern hemisphere, and from the north-west in the southern.

I was once waiting in a station, when a train came by almost without slackening speed. Some one in the train wanted to throw a parcel to the station-master, who was standing at that end of

the platform at which the train came in. But the man who threw the parcel forgot that it shared in the motion of the train; he threw it at the instant he passed the station-master, and it fell at my feet, though I was standing at the other end of the platform. The parcel moved with nearly the same speed as the train, and travelled the length of the platform before it reached the ground. He threw it straight out of the window at the station-master, as he would have done if the train had been standing still. It struck the ground as if he had aimed it at me. So the upper current, which starts from the Equator in a northerly direction, seems, a good while before it comes near the North Pole, to blow from the south-west, because when it started it shared in the motion of the earth near the Equator. And that current which started from the Equator towards the South Pole, seems to blow from the north-west. While the trade-winds are blowing steadily in their usual direction, clouds are often seen carried by this upper current in a contrary direction.

I have more to say about the winds, but I must ve it for my next letter.

From your affectionate Aunt,

RACHEL.

V.

My dear Children,

Perhaps you are wondering by this time why our winds do not always blow from the north-east. Look again at our orange, which represents the earth. You will see that a circle drawn upon it at a little distance from the Pole (to represent a parallel of latitude) is much smaller than the Equator; therefore the winds would be crowded together about the Poles if they went on their way as regularly as I have described. The upper current sinks down, too, as it gets cool. By the time it has got as far north as the Peak of Teneriffe, it has sunk so low that at the top of the Peak there is often a strong south-west wind, while the north-east trade is blowing at the bottom. So some of it is carried back with the trade-winds to the Equator, without ever reaching the Poles. The remainder is constantly fighting for the mastery with our north-east winds. In our country, the warm southerly winds oftenest gain the victory.

Many other things help to make the winds irregular. I told you, in one of my old letters,

that some things both get heat and lose heat more quickly than others. Earth does, compared with water. So the land sometimes grows hot in the sunshine, and heats the air above it, causing a draught to flow in from the cooler sea. At night the land becomes cooler than the sea, and the draught is the other way. This is very general along the coasts in tropical countries. Indeed, it is only over the sea that the trade-winds blow as regularly as I have described.

I for one am glad to live in the region of variable winds. It would not be pleasant to have the wind always in the same quarter: and if our only wind were the dry, biting north-easter, we should be unable to grow many plants which flourish with us now, and Old England would be a far less pleasant place to live in. It is the south-west winds, too, which bring us our plentiful rains, making our grass and trees so green. Let us see how this comes to pass.

You know that there is in the air a quantity of water, which is quite invisible, because it is in a state of vapour. It is that, you remember, which -les in dew upon the cold grass, because air can more watery vapour when it is hot than when

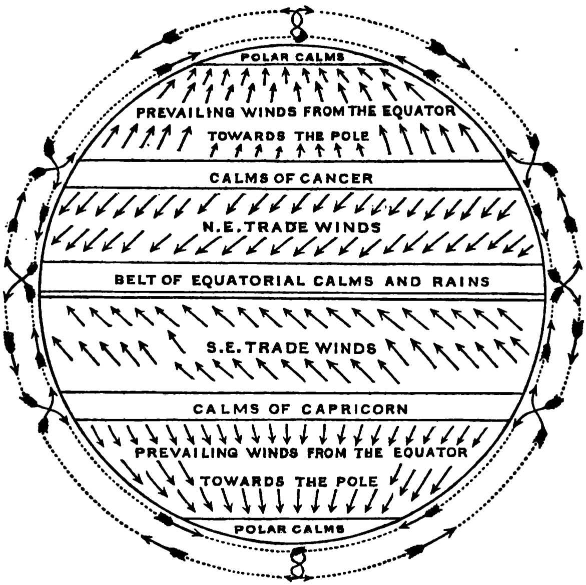
it is cold. Our north-east winds, coming from cold regions, grow warmer and warmer as they travel, and able to hold more and more watery vapour, so that they dry up every moist thing which they find in their path. Our south-west winds, on the contrary, come from warm countries to a cold one, and grow less and less able to hold the watery vapour they took up when they were blowing, as trade-winds, over tropical seas. So the vapour which they can no longer hold falls to the ground as rain, especially when the wind is chilled by striking against a mountain colder than itself. Thus nearly all our rain comes with a south-west wind.

But this is not all. If you look at a globe, or at a map of the world, you will see that in the northern half of the world there is more land than water, while in the southern half (*hemisphere*, as it is called) there is more water than land. Yet it is a curious fact, that more rain falls in the northern hemisphere than in the southern. When rain falls, some of it is sucked up by plants, some of it is dried up, and passes into the air again (is 'evaporated'), and the rest runs into the ground to feed the springs and brooks, which

when they join make rivers. So where we find a large river, we may conclude that there more rain falls than is evaporated. Now, if you look again at the map, you will see that nearly all the great rivers of the world are to the north of the Equator. In Australia there are no large rivers, and in the greater part of the country water is very scarce. In South Africa there are none; in South America only two south of the Equator, the Amazon and the Plata; while in the northern hemisphere we have the Mississippi, the Ganges, the Indus, the Orinoco, the Danube, the Euphrates, the Nile, and many others.

From this it seems that in the southern hemisphere less water falls as rain than is taken up by the winds from the surface of the sea; while in the northern hemisphere the rain-fall is so much greater than the evaporation, that great quantities of water flow down to the sea in rivers. How is this to be accounted for? It is supposed that when the north-east and south-east trade-winds meet at the Equator, and rise up to form the upper currents from the north-west and south-est, the two currents *cross over*. Each current, —d of *turning back* to the place whence it

came, as soon as it has risen above the under current, goes onwards, but as an upper current,



Copied (by kind permission of Messrs. Sampson Low, Son, and Marston), from Maury's 'Physical Geography of the Sea.'

not on the earth's surface. Thus the south-east trade-wind, laden with all the moisture which it

has taken up from the southern seas, rises up at the Equator, parting with much of its moisture as it does so, for it is almost always raining there. Then it goes on its way as the south-west upper current, sinks again, as I told you, farther north, and reaches us as the warm, damp, south-west wind. Meanwhile, the north-east trade-wind becomes the north-west upper current of the southern hemisphere, and carries to the people of Australia far less water than their south-east trade-wind brought to us, because it has blown over less sea than that did.

It had been for some time supposed that the two trade-winds crossed in this way, when in a very unexpected manner it was proved. Showers of curious red dust sometimes fall upon ships near the Cape Verd Islands and in the Mediterranean. For a long time no one knew what this dust was, nor where it came from. At last, it was examined with a microscope, when it was found to be made up of little shells and dried insects, of very uncommon kinds. Such insects were known to live in South America (in certain parts over which the south-east trade-wind blew), and were not known anywhere else. They must have been caught up

by some storm or whirlwind in the dry, dusty plain, and carried by the wind, first for a little way near the surface of the earth, then, after passing the Equator, they were carried onwards as a south-west upper current. When the current cooled and sank towards the ground, this dust fell too. This was the only way in which the fall of red dust in the Mediterranean could be accounted for. The wind which was carrying it must have crossed the Equator. In the same way, water is brought from the great seas of the southern hemisphere to the thickly-peopled countries of the northern hemisphere, making them fertile and pleasant to live in. Thus, you see, the expansion of air by heat gives rise to winds, and keeps the air constantly moving, all over the earth's surface. You will see how very important this is, when you learn how the air is spoilt by our breathing, and how necessary it is that it should travel from places where there are many men and few plants, to places where there are many plants and few men.

Believe me your affectionate Aunt,

RACHEL.

VI.

My dear Children,

I have a little story to tell you. The other day, in a cottage near here, some one was careless enough to leave a match on the floor. A little boy, too young to know that he ought not to meddle with such things, found this match, and rubbed it against the brick floor. In another moment his pinafore was on fire, and he had run into the garden screaming for Mammy. But Mammy was out at work, and the sister who ought to have looked after poor little Tommy, and who had been playing in the road instead, was too much frightened to do anything but scream. Happily, a woman was just then passing the gate, who had all that was wanted to save the little boy—a knowledge of what to do, presence of mind and courage to do it, and a thick woollen shawl. She caught him in her arms as he ran into the road, and wrapped him in her shawl, rolling it tight round him, and where the flames burst out again, crushing them out with her nds, without stopping to think of the pain. So w, though poor Tommy is badly burnt (for the

fire spread quickly as he ran about), we hope that he will be well before very long. If the woman had been a little later, and the child had been allowed to run about in the air only a minute longer, it might have gone hard with him.

I have no doubt that you have been taught long ago what you ought to do if your clothes catch fire; that you ought on no account to run about, but keep as still as you can, lying down, and rolling yourself up in a hearthrug or blanket, if possible. But do you know *why* you should do this? This accident of little Tommy's has made me think that I had better write you a letter or two about Flame, what it is, and how it is fed.

First of all, then, the lower part of a flame is hollow. You may see that by pressing a card or piece of paper straight down on to a candle-flame, taking care not to leave it there long enough to catch fire. You will find it charred in a ring with an uncharred piece in the middle. What is there inside the flame? Clearly it is gas or vapour of some sort, and it has a very unpleasant smell, as every one knows who has ever blown out a candle. It is the vapour of the wax or tallow of which the candle is made. When first we hold a lighted

spill to a candle, it melts some of the wax on the wick, and sets it on fire. This makes a very small flame, but it is hot enough to melt more wax and set fire to that, and so on, till the whole cup of the candle is filled with melted wax, which creeps up the wick and grows so hot, that most of it turns to vapour, and rises to feed the flame. The flame is found only where the outer air meets and touches this vapour. When you blow out a candle, it goes on rising for some moments after the flame is gone, and if you hold a lighted spill quickly an inch or two above the wick, the rising stream of vapour will catch fire, and the flame spreading downwards, will relight the candle. The white fumes are in fact cooled vapour, and are made up of tiny particles of wax, which has passed back again into its old solid form. If you examine a piece of paper which has been pressed down on the flame, you will probably find that the part inside the charred circle is more or less greasy. The coolness of the paper has condensed the vapour there. Or if you hold in the inside of a candle-flame one end of a little glass tube about three inches long, making it slant upwards a little, you may see the white fumes rising from the upper

end. A long tube does not answer, because the vapour is thoroughly chilled in passing along it, and collects in a spot of grease on the inside of the tube before it reaches the farther end.

The next question is, whether all kinds of air are equally good for keeping a candle alight? Put a candle under a tumbler or glass jar; it will very soon go out, though the jar is still full of air of some kind. For the candle has not destroyed the air, or driven it out. As for *destroying* air, or anything else, properly speaking, the thing cannot be done. We can *change* things in a countless variety of ways, hiding them away, and making them invisible to our eyes, but we cannot destroy any part of them, any more than we can make it. We may put together, but we cannot make; we may pull to pieces, but we cannot destroy. So we may be sure that the air in the tumbler is not destroyed. Is it driven out? No; or at least not much of it. You may prove that by putting your candle in a saucer of water before turning the tumbler over it. If you think a little, I am sure you will be able to tell what ought to happen if the air had been driven out. The water would rise into the tumbler, like the

juice of a tart into the cup, and for the same reason. If the tumbler is large and the flame small, it may go on burning long enough to heat the air and expand it, so that some of it escapes in a bubble through the water in the saucer, and then when the air cools, the water will rise a little way into the tumbler. But this does not happen till the candle has long been out, and the air is cool again. Besides, by far the greater part of the air is left in the tumbler. So the reason that the candle goes out cannot be that there is no air in the tumbler. It goes out because it has fed on the air and changed it, so that it can no longer feed on it.

Let us see if we can find any other way of showing that air in which a candle has been burnt is different from fresh air. Take a little piece of quicklime, such as is used in making mortar. Pour soft water on it, and let it settle, or strain it through muslin. It will look just like common water. You may shake it about almost as long as you please in fresh air. You are pretty sure to grow tired before you see any change in it. But pour it into the saucer instead of the pure water in which you put the tumbler

just now. When the candle has gone out, shake up the limewater with the air which has put it out. It will become white and thick, like milk. This is a proof that the air in the tumbler has been changed by having a candle burnt in it.

Now I must remind you of something which I told you in one of my old letters. I told you that the air is made up of two gases mixed together,—one a very sluggish gas, called nitrogen, and one a very active gas. The active gas is called oxygen; and it is the oxygen of the air, uniting with something in the candle, which makes the candle burn. But only about one-fifth part of the air is oxygen; and when the candle has used up all it can get at, it goes out for want of food, for it cannot feed on the other gas, which makes up the greater part of the air. By 'using up' I mean not destroying, but *changing*. I will try to explain something about this change.

Everything we see in the world around us is made of comparatively few materials. Only about sixty simple substances or '*elements*' are known. It is believed that none of these can be pulled to pieces or separated, as I told you we can separate water into the gases which make it up; and it is

believed that everything which we see or feel is made of some of these sixty or sixty-three substances; that mixed together in different ways and different quantities, they make up minerals and vegetables, and even the bodies of animals. Even learned men know very little of *the way* in which God has made plants and animals out of these lifeless elements; but they know the fact that He does it; for when they examine the substance of a plant or an animal's body, they find in it certain of these elements with different qualities, according as they are mixed in different proportions. Thus we learn that God has seen fit to use only about sixty kinds of material to build all this world, with everything upon it—all lifeless things, and all things which live and grow—all things useful as food, and all poisons! Truly a wonderful variety of things to be formed out of such simple materials!

But we must go back to our candle. When chemists examine the materials of which a candle is made, they find them made chiefly of two elements, Carbon and Hydrogen. We will talk the carbon first. Oxygen is an element too, it has, so to speak, a great affection for both

carbon and hydrogen. They have what is called a '*chemical affinity*' for each other; that is, the atoms of carbon and oxygen are drawn together by a wonderful force, about which I can tell you very little. When we put a lighted spill to a candle, first we melt the wax, then it changes to vapour; then the vapour grows hotter and hotter, and the hotter it grows, the stronger grows its attraction for oxygen, till each atom of carbon rushes to an atom of oxygen, and they join to make one double atom, which is quite different from either of the elements which make it up. Or if the supply of oxygen is plentiful, two atoms of it join one of carbon, and make a triple atom, quite different in its properties from either carbon, oxygen, or the double atom we have just spoken of.

You know that when you knock two hard things together you can warm them. If a piece of iron is hammered long enough and hard enough, it grows quite hot. It is the same with the atoms of carbon and oxygen. Though the space across which they move is perhaps smaller than we can imagine, yet they come together with such a clash that it makes them red-hot, or white-hot. It is

these white-hot atoms which make up the candle-flame. They do not keep their heat for long, but give it up to fresh oxygen and fresh candle-vapour, so that a flame once lighted goes on burning as long as it can get fuel and a plentiful supply of oxygen. First, each atom of carbon joins with one atom of oxygen; but before it can pass out of the flame, in other words, before it has had any time to cool, another atom of oxygen joins them, and they make a triple atom, containing one of carbon and two of oxygen. The substance made of these triple atoms is called carbonic acid gas. This it is which is in the tumbler (mixed with nitrogen) after the candle is gone out, instead of the pure oxygen, which was the only thing mixed with the nitrogen when we lighted the candle. The oxygen is still there, but it has so much carbon joined with it that it cannot join with any more from the candle. It is quite useless as far as feeding the candle is concerned, though, as you will see, it is by no means useless in other ways.

In my next letter I will tell you more about ›nic acid.

VII.

My dear Children,

The more oxygen there is in air, the more brilliantly will a candle burn. It is because a thick shawl keeps the air away from a flame, that it is such a good thing for putting out accidental fire. When there is too little oxygen in the air, the candle first burns dim, and then goes out. This sometimes happens in very crowded rooms, and then it is high time to open the windows. For where a candle burns dim, a man cannot breathe properly; where a candle goes out, a man cannot breathe at all. Our life is as dependent on a plentiful supply of oxygen as is the flame of a candle, and suffocation is as certain in bad air as in water. And this brings us to speak again of bad air, or, more correctly, carbonic acid. It sometimes collects in empty wells and mines. The miners call it 'choke-damp.' When a workman goes down an old well to clean it, he lowers a candle first (if he is a wise and experienced man), to see if it is safe for him to venture. If the candle goes out, he knows he

must do something to remove the bad air before he can go down in safety.

You know already one way of making carbonic acid—by shutting up a lighted candle in a close vessel until it goes out. But this is not pure carbonic acid. Watery vapour and other things are mixed with it when made in this way, and you will find the following way more convenient for making enough to try experiments with:—Break up some chalk into small pieces, and pour acid over it, in a good-sized jar. (Vinegar will do, but muriatic acid is better, only you must take care not to spill it, for it is strong enough to burn holes in your clothes.) Now, chalk is made up of lime and something else. When acid is poured over it, a fizzing noise is heard, as if the liquid were boiling,—the acid unites with the lime in the chalk, and sets free the other part of it. This other part is carbonic acid, which, bubbling up through the acid, makes the fizzing noise. Is it not strange that we should get a transparent, invisible gas from a hard, solid substance like chalk? It is sometimes called 'fixed ' because it is locked up in a solid, and may be set free. We might have got it equally

well from marble, if we had pounded the marble, and poured over it some strong acid, much stronger than vinegar.

Carbonic acid is heavier than air, and will lie in the jar for some time without mixing with the outer air, if you put only a card over the mouth to shield it from draughts. That it does so, is enough to prove it heavier than air; but this may be proved in another way. An empty cup or jar is placed in a delicate pair of scales, and balanced with a weight in the other scale-pan. The jar of carbonic acid is held as it would be held if water were being poured from it into the cup. Nothing is seen to fall; but in fact, carbonic acid is being poured out, and it will weigh down the jar. The weight which was heavy enough to balance it when full of air, will not be heavy enough when it is full of carbonic acid. It is almost startling to see the scale-pan sink, when, so far as the eye can tell, nothing has been put into it. It is only one instance, among many, of how one's eyes may mislead.

To make quite sure that we have something in our jar different from the common air which filled it a minute ago, we have only to dip a lighted

spill into it, and the carbonic acid will extinguish it at once. Or you may pour a few drops of lime-water into the jar, and shake it about so as to mix it up with the carbonic acid. (I am supposing now that you have poured the carbonic acid into a clean jar, so that you can add lime-water without mixing it with the chalk and vinegar.) This is a sure test by which we can tell when we have carbonic acid; when lime-water grows milky by being shaken about, we may be sure it has laid hold of carbonic acid. When this gas touches lime-water, it rushes to the lime in it, and joins with it. You remember that when we pulled chalk to pieces, the vinegar took hold of the lime and left the gas behind. Here we have lime and carbonic acid coming together, and they are what chalk is made of. It is tiny morsels of something like chalk, mixed with the lime-water, which give it the milkiness by which we know that carbonic acid is there. It does not matter how you make carbonic acid it always has this effect on lime-water. You let a bit of burning wood float on the top of -water in a half-empty bottle, and, when the gone out, shake the bottle. Or you

may catch the heated air which rises from a candle in a bent tube, and make it bubble through lime-water. Or you may add lime-water to soda-water (of which I shall say more presently). In all these cases you have the milkiness produced. Or you may burn a diamond; for, strange as it seems, diamond and charcoal are both made of carbon. Black crumbly charcoal, and the clear, hard diamond,— it is indeed hard to believe they are the same element in different forms; yet, by being burnt, both change to carbonic acid, and then there is absolutely no difference between them. The cleverest chemist in the world could not tell whether a certain jar of carbonic acid had been made by burning charcoal, or by burning diamonds.

There is yet another way of making carbonic acid. Every breath that we draw we change some of the oxygen of the air into carbonic acid. The carbon which does this is to be found in our blood, and it is the burning of this—the heat given out when it unites with the oxygen which we breathe—that is the chief cause of the warmth of our bodies. Take a wide-necked bottle, half full of lime-water, and pass through the cork two

glass tubes, of different lengths, so that one of them reaches down into the lime-water, and the

other does not. Put your mouth to the shorter tube, and draw your breath *inwards*. You draw air out of the upper half of the bottle, and, to supply its place, air comes in through the longer tube, and bubbles through the lime-water. You may go on breathing in this way for a long time, without making the lime-water milky, if you take care that no air passes *from your mouth* into the bottle. But now put your mouth to the longer tube, and breathe *outwards*, so that the breath from your lungs (instead of fresh air) passes through the

lime-water. Very soon it will be quite white and milky. Or take a glass jar, in shape like a stoppered bottle without a bottom. Put it in a basin with water (you will find out the best quantity of water after a trial or two); covering the mouth of the jar with your mouth, breathe the air that is in the jar. As you take it into your lungs, the water will rise

in the jar. (I hope there is no need for me to explain why.) Breathe out the air into the jar again, driving out the water; then breathe the same air again, and breathe it out once more. By this time I think the air in the jar will be so changed that it will put out a lighted spill.

This shows how necessary it is to open our windows and let in fresh air in place of what we have breathed and spoiled with carbonic acid (and other poisons too). It shows too how dangerous it is to warm a closely shut-up room with charcoal. There is no smoke from charcoal, and so people are apt to warm rooms which have no chimneys by keeping in them pans of burning charcoal. But the fumes of charcoal are hot carbonic acid, mixed with another gas quite as poisonous. True they do not make us cough, and bring tears into our eyes as coal-smoke does, but they are none the less poisonous for that.

I must not speak of carbonic acid as poisonous without saying a word or two in explanation. It is poisonous to breathe, but not poisonous to eat. We drink it in soda-water, and ginger-beer, and all effervescing drinks. The little bubbles in them are made of carbonic acid. Great quantities of

it are made in brewing beer, not on purpose, but because it is given off by the half-made beer. Until a few years ago it was thought by the brewers to be quite useless, even dangerous if any one fell into the vats where it lay, and a great trouble to get rid of; but now bakers use it for making a sort of bread called 'aerated' bread. Instead of putting yeast to the dough, they send through it a stream of carbonic acid, which answers the same purpose. So it always is; the more people know, the more they find a use for what they once thought useless. Indeed, the more people know, the less willing they are to call anything useless.

All over the earth men and animals are breathing in oxygen and changing it to carbonic acid. Every fire and candle that burns has the same effect in its degree. What is to prevent all the oxygen in the air from being used up, and turned to poison? I will tell you.

How fast plants grow in the bright summer weather! Where do you think all the leaves and flowers come from which appear so quickly that one can almost see them grow? What material is used to form them? In some strange and

beautiful way, which we know little about, plants have the power of feeding on the carbonic acid which floats about in the air. When the sun shines on them, they drink it in at the pores of their leaves. They pull it to pieces, and use the carbon to build up their branches and leaves, while they let the oxygen go free for men and animals to breathe. It is only in the daytime that plants are able to do this. They cannot pull to pieces carbonic acid in the dark. They *use up* some of the sunshine in doing it. A certain quantity of light and heat is used up in taking one ounce of carbon from carbonic acid, separating it from the oxygen, and storing it away in the form of wood; and, strange to say, just as much light and heat is given out again when the same quantity of wood is burnt. As much carbonic acid was pulled to pieces to make the wood as is made again when the wood is burnt; and the quantity of sunlight and heat used up in the pulling to pieces is just equal to the quantity of firelight and heat given out when the wood is changed again to carbonic acid.

I dare say you know that coal is made of the trunks of trees which grew on the earth long,

long ago, before men lived there. They stored up sunlight and heat as they grew, ages ago, and we feel it now when we burn gas and coal. Is it not strange that the sun which shone on the earth ages ago should make any difference to us? You would never have guessed that it was possible, but it is really true. All the fruit and vegetables, too, that we eat, have used up sunshine in growing, and when we eat them, the materials of which they are made pass into our blood. You remember that the heat of our bodies comes chiefly from the oxygen of the air uniting with the fuel contained in our blood. So the heat of our bodies even comes, in this roundabout way, from the sun.

At first sight, it seemed as if carbonic acid were a mischievous, poisonous thing, and it was rather dreadful to think how much of it was being made all over the world. But see how beautifully it is contrived that it shall be not only harmless but useful,—necessary, indeed, for without it how can plants live? and without plants how ·ıld animals and men live? Surely we may ·n from this to hesitate before we call anything ll· creation common or unclean!

One word about the other substance which is mixed with the carbon in the candle, and then I will end this long letter. I told you in one of my old letters that this 'hydrogen,' uniting with the oxygen of the air, made water, and I told you how to find the water, by holding a cold spoon over the flame. The *heat* of the flame is chiefly due to the hydrogen and oxygen uniting, as its *light* is chiefly due to the carbon and oxygen, so you see that when water is made heat is produced. Now water is *un*made by plants in sunshine, just as carbonic acid is. They store away the hydrogen, and let the oxygen go free. To do this, they use up sunshine (as they do in pulling carbonic acid to pieces), just so much of it as is equal to the quantity of heat which was given out when the water was formed. When the plant is burned (or eaten), and the hydrogen joins the oxygen again, we find in the watery vapour which rises from the flame (or from our lungs) just the same quantity of heat.

VIII.

Now for a few facts about Oxygen. But we must get our oxygen before we can examine it. The following is one way of doing so:—On a fine, hot day get a handful of mint. Fill a glass jar or tumbler with water, and turn it upside down in a basin of water. Put your mint into the glass, taking care not to let in the air. Slip a saucer underneath the glass, lift it out of the basin, and set it in the sun. Before evening bubbles will have collected at the top of the glass, and these bubbles are oxygen. I think you will know how they get there when I tell you that carbonic acid is very easily dissolved in water, so that almost all water has more or less carbonic acid in it. This is pulled to pieces by the mint in the hot sunshine.

But this is a slow and tedious way of making oxygen. You would have to renew your mint for many days one after another before getting enough oxygen for your purpose, and there are many chances against an experiment which has to be so long in hand ever coming to a successful en   you would let in a great bubble of

air as you changed the mint, and so spoil all the oxygen you had already collected, or the cat would upset the whole thing, or some other misfortune would happen before your jar was full. I will tell you another way to make oxygen.

Get some chlorate of potash at a chemist's. Three or four pennyworth will be as much as you want. Crush it. Half fill the bowl of a tobacco-pipe with the powder, and stop the mouth with clay well pressed down. Put the bowl over the flame of a candle. Oxygen is given off from this

substance when it is heated, and will be driven through the stem. To collect it, put the end of the stem in a basin of water, under an inverted jar full of water. The gas rising into the jar drives out the liquid. The most convenient sort of jar is like that which I described before, a stoppered bottle without a bottom. Your great difficulty will be to prevent the gas from escaping through cracks which are apt to form in the clay as soon as it is hot. It will

need some little patience and patching up of the cracks with fresh clay before your jar is filled. If you mix the clay with chopped hair or tow it will dry more evenly and be less likely to crack. When you try the experiment for yourselves, you will, no doubt, meet with various little difficulties of this kind, and you will find great pleasure in devising means of getting over them. Failure often teaches us quite as much as success, if we can but find out the reason we have failed. Only we must have courage and patience, remembering that there is even more pleasure in success when it follows failure than when it has been easily gained. You may sometimes find out where oxygen is escaping by putting water over the clay and watching where the bubbles come. Sometimes you may find it well to empty the pipe, to see if the powder is caked together at the entrance of the stem, so as to choke it up. When the jar is full, many and beautiful are the experiments which may be made with it. Only, unless your jar is a very large one, you will have to renew the supply of oxygen each time. Blow out a candle, so that only a little bit of wick remains red-hot; plunge

it into the jar of oxygen, and it bursts into flame again. So great is the attraction between the oxygen and the materials of the candle, that even the little heat left in the wick is enough to make them unite. Or you may put a morsel of sulphur in a sort of little spoon, and lower it into the jar. It will burn with a bright yellow flame. Charcoal, when burnt in oxygen, throws out brilliant sparks. Even iron and steel will burn in it, and the hard, bright diamond itself; but some of these want greater heat to set them on fire than you have at your disposal. The little spoon which holds your sulphur or charcoal should have its handle bent straight up, and a bit of tin or tin-foil, fastened to it at a convenient height, so as to serve for a light moveable stopper to the jar. If the mouth of the jar were quite open, the oxygen might escape too soon; if the stopper were there, it would be too heavy for the heated gas in the jar to lift when it had to make its escape, and it would have to find its way out in some other less convenient way,—perhaps upsetting the jar by making its way out in a great bubble at the bottom.

And here I had better warn you to remember

the effect of the pressure of the air on the level of liquids. Before taking the stopper out of the jar, you should see that the level of the water inside is the same as that of the water outside it. If it is lowest in the jar, it will rise when you take out the stopper, driving out some of the gas. If the contrary is the case, the water will sink in the jar, and air will therefore enter it, and mix with the gas.

Oxygen sometimes unites with other elements quickly, and sometimes slowly. We have seen that when it is pure it unites with iron quickly and we say that the iron *burns.* But the oxygen in the air, mixed up as it is with sluggish nitrogen, can unite with iron slowly, and in this case we say that the iron *rusts.* Iron will not burn in pure oxygen unless it is heated to begin with, and it will not rust in the air unless it is wetted to begin with. The oxygen enters into the water, is dissolved in it, and in that state it is more ready to combine with the iron than it was before, and a spot of rust is formed. This may get quite dry; but the mischief has begun, and will not stop, nless the rust is rubbed away. For the oxygen he air is very ready to combine with rust, wet

or dry, and the rust passes it on to the part which is not rusted. The dry iron can take it from the rust, though it cannot take it from the air.

Now this rusting is in reality a slow burning, though we are not in the habit of calling it so. When an ounce of iron burns in pure oxygen it gives out a certain quantity of heat, and as it burns quickly it gives out all this heat in a minute or two. Just the same quantity of heat is given out when an ounce of iron turns to rust, but we do not feel it, because it is spread over many months. Once a quantity of wire covered with gutta-percha was lying coiled up in the hold of a ship. It was meant for a telegraph, but water got to the wire at the beginning of the voyage, in spite of the gutta-percha. All through the voyage the rusting went on without any one knowing it. When they began to unload the ship, they found that so much heat had been produced by the rusting of this large quantity of iron wire as it lay coiled up in heaps, that the gutta-percha covering was melted by it, and the telegraph wire was spoiled.

The same sort of thing happens in haystacks when the hay has been stacked while damp. The oxygen of the air is dissolved in the moisture

the hay; then it combines slowly with the hay, and that produces heat; and sometimes this heat is great enough to enable the oxygen of the air to unite directly and quickly with the hay, without waiting to be dissolved in water. In other words, the stack takes fire.

I have spoken of ventilation when telling you about the poisonous carbonic acid which we must get rid of; but now we are speaking of the health-giving oxygen which we want to let into our houses, I cannot resist mentioning it again. For the more we learn about this sort of thing, the more power we may expect to have in driving away many fearful forms of disease. In old days, when people thought very little about fresh air, or fresh water, or cleanliness, the dreadful plague used to visit England, as you have read in your 'History.' We have attended more to these things during the last 200 years, and the plague has not visited us; but cholera still comes now and then, and this is not only a misfortune but a disgrace, for if no one had to drink dirty water, or to live in dirty, over-crowded houses (where the air has e breathed many times over before it makes for fresh air), then cholera would not come.

So wise men tell us, who have done their best to learn the truth about it.

You may have been puzzled to hear that we must open the window at the *top* to let out the bad air, or carbonic acid, which we breathe out, when you have also heard that carbonic acid is heavier than air. But you must remember that it is hot when it comes from our lungs, and that makes it lighter than the cold air which has not been breathed.

Besides the oxygen in the air, there is four times as much of another gas called nitrogen. I told you in one of my old letters about this gas, about its sluggishness and unwillingness to unite with anything else, and about its use in keeping the lively oxygen in check; so I will not say it over again here.

IX.

If I were to ask you, 'What is inside a pair of bellows?' I dare say you would answer, 'Nothing.' But what comes out at the nozzle when you squeeze the boards together? Air, to

be sure; and so of course there was air between the boards to begin with.

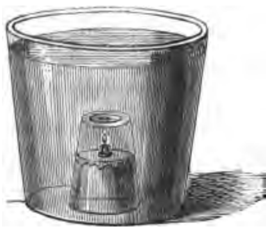
We are so little aware of the air when it is still and we are still too, that it is a surprise to most people to learn how much resistance it can make when it is strongly squeezed together, or when anything moves very quickly through it. Try to run quickly with an open umbrella in front of you, and you will soon see that air is very different from 'nothing,' and requires a good hard push to force it aside in any quantity, or with any quickness. It is still harder work to run holding the umbrella handle foremost, for you catch some of the air in the hollow of the umbrella, and have to push it before you. Or in fanning yourself, you find that it takes some force to set air in motion. It is not the *weight* of the fan which makes it hard work to fan yourself, for it is very easy to move the fan backwards and forwards when it is closed, and it is as heavy then as when it is open. The only difference is in the quantity of air which is set in motion by it.

When you separate the boards of the bellows, rushes in through the hole in the bottom d, which is covered, as you can easily see,

with a 'valve,' or flap of leather, opening only inwards, so that air can pass in but not out. When you press the boards together, the air cannot escape by the same way, because the valve falls and is tightly closed by the air itself pushing against it; and as air resists being squeezed together, it rushes out at the nozzle. If you turn the bellows upside down, you cannot work them so well. It is only by a violent jerking motion that you can work them at all. Why is this? The weight of the valve keeps it open in gentle blowing, so that the air can get out the same way that it got in. But if the boards are violently jerked, the air behind the valve is in such a hurry to get out that it slams-to the valve in front of it, and stops up the outlet. It is a case of most haste, worst speed, and the air has to go out through the narrow passage at the nozzle.

In an air-gun or a pop-gun, air is squeezed up into a small space, and it is its 'elasticity' (the force with which it returns to occupy the same space that it did before it was squeezed) which sends out the bullet. It drives out the bullet as it makes its escape by the only outlet left to it.

When a jar is filled with water, nothing else can be put into it without driving out some of the water, and the same is true of air, except in cases like the pop-gun, where the air is so much confined that it cannot make its escape quickly enough to avoid being squeezed together. When a jar is full of air we cannot *see* anything in it, and so we are in the habit of saying that it is empty; but, strictly speaking, this is by no means true. Turn a tumbler or a large jar upside down, and lower it into a basin of water. If it were really empty, you know the water would rise and fill it, but instead of that the surface



of the water is lower inside the jar than outside. If you pour more water into the basin, so as to cover the jar, the water inside it will not rise to the top. A little light (such as a wax-match or a taper) on a cork, or in a little paper boat, set floating on the water under the jar, will go on urning till it has used up the air. What puts out is not the water but the want of air, for

the taper is not wet when it comes up again. If your jar is large and your flame small, and you are quick and skilful, you may send it as many times as you please to the bottom of the basin without putting it out, especially if you take care to let in fresh to take the place of the half-used air in the jar between each journey, instead of sending it down again the moment it comes up.

This jar is, in fact, a little diving-bell. The men who go down in diving-bells at sea sit in the upper part of the bell, and do not get wet, because the air keeps out the water. They would very soon be suffocated, shut up with so little air, but there are long pipes, reaching from the roof of the bell to the top of the sea, and fresh air is forced down these pipes to the men by means of a pump.

No doubt you will be surprised to hear, that but for the resistance which air makes to anything moving through it, light things would fall to the ground as quickly as heavy things,—a bit of thistledown as quickly as a stone. They are actually seen to do so in a tall glass vessel from which the air has been taken by an air-pump. The reason that the stone falls the most quickly

in air is this: the thistledown has much more surface in proportion to its weight for the air to press against. I will try to put this more plainly. A lump of gold, weighing (say) half an ounce, falls quickly to the ground because it has to push aside very little air; but if the lump were beaten out into gold leaf, it would be very different. The thin leaf would cover a large space; it would have a great deal of surface, and could not fall without pushing in front of it many times the quantity of air which had to make way for it when it was in a lump. But its weight, the force which draws it towards the earth, is just the same as it was. So it is only very slowly that it can overcome all the resistance of the air. It is like the difference between running along with an open umbrella in front of you, and with one which is tightly rolled up. I will tell you of a case in which this resistance is very important.

You know how hot you can make two things by rubbing them together. You have heard of savages striking a light by rubbing dry sticks together. We light our fires with lucifer matches, but the heat which sets fire to the very inflammable substances of which they are made is caused by rub-

bing, or 'friction,' as it is called. But you would not think that the thin invisible air could give much warmth to anything which rubbed against it. Yet it does. Have you ever seen a shooting star—a point of light darting across the sky like a messenger between the stars? But shooting stars, or 'meteors,' as they are more properly called, are not really anywhere near the fixed stars which we see shining in the same places year after year. *They* are great suns, so very far away that nothing I could say would make you understand the distance. It is too great for any of us to understand or imagine. And the meteors are less than a hundred miles away. What do you think they are? I dare say you have been told that the earth is not the only world which travels round the sun. There are other worlds, called planets, some smaller than our world, some larger, which move round the sun too. They reflect the sun's light to us, and we see them shining in the sky like stars, only that when we watch carefully from night to night, we may see that they change their places. And besides these planets, there are crowds of little bodies (made of much the same materials as those of which our earth is

made, some weighing several tons, some perhaps no bigger than a pistol-ball), which move round the sun in companies. It is believed that there are several belts, or rings, of these little moving models of worlds at different distances from the sun, which is in the centre of them all; but no one has yet seen them, for though the sun shines on them as on the bigger planets, they are too small for us to distinguish, even with the best telescopes now made. How, then, do we know that they are there? In this way:—When our earth in her journey crosses one of these belts, or comes near to it, little meteor-stones become entangled in the air which surrounds the earth. It must be very thin where first they touch it, but it hinders them, and they fall towards the earth. Now and then one of the larger ones falls upon the earth, but most of them are small, and are burnt up,—changed to vapour before ever they reach us. Can you guess what it is that burns them up? The heat which is caused by their rubbing against the air! You know how thin the air is great heights—only think how fast the meteors move to make friction enough to set them e! They do indeed travel fast; some of

them move nearly twice as fast as the earth in her journey, and she moves nineteen miles a second. During the moment that they are burning—between the moment when they first take fire, and that when they pass into smoke or vapour—we see them, and call them shooting-stars. You may expect to see many of them, if you look out at night about the 10th of August and the 13th of November, because on those nights every year the earth is crossing one of those belts of which I have spoken. Sometimes on these nights they come in such numbers that it would be very dangerous, if they were not burnt up before reaching the ground. So you see that but for the resistance which the air offers to those quickly-moving meteors, we should know by experience what it is like to be in a besieged town during bombardment.

I have now finished what I have to say about Air. My object in writing these letters has been to make you interested in common things, such as Water and Air. If once you know enough to feel an interest and love for them, and a wish to know about them, you will find it a source of nev

ending enjoyment. For where there's a will there's a way; and if you wish to know more, the wish is pretty sure to be gratified, either by means of books, or by using your own eyes and heads in watching what goes on around you. When you are older, and are troubled (as we all are sometimes) by seeing things go wrong which you cannot mend, you will find it a great help and comfort to turn your thoughts to such things as I have been writing about. For nothing goes really wrong except by some one's fault or ignorance, and what we call the laws of Nature are beyond any man's power to meddle with. They are God's laws, and (unlike His higher laws of right and wrong) they are never broken, so all is order and beauty there. I cannot say how glad I should be if what I have written teaches you to see, and love, and enjoy that beauty.

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LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET